MACHINE CONSTRUCTION AND DRAWING

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PREFACE.

A LONG experience of teaching Machine Construction and Drawing to students of many kinds has led to the conclusion that in order to be able to produce in a reasonable time a working drawing of, say, a machine or an engine detail, a student must know thoroughly certain fundamental facts. He must, for instance, be familiar with the proportions usually adopted for such simple details as rivets, bolts, keys, cotters, and so on.

The plan followed in this book has been first to describe these details briefly, and then to give what may be termed their usual empirical proportions—which are obtainable without calculation. In any subsequent drawing given in the book or to be made by the student—in which these simple machine or engine details occur, the dimensions have to be determined from the empirical proportions previously supplied. In this way the student gains unconsciously a complete familiarity with the commonly occurring simple details. In special cases, of course, calculations are necessary, and the results obtained by actual experience in particular instances must be utilised. The student is shown, by numerous examples, how these processes are performed.

An examination of the contents of the volume will, it is believed, show that an unusually large number as well as a great variety of machine and engine details have been brought together in the book. It should be understood, however, that no attempt has been made to include every essential with which a machine draughtsman should be acquainted.

After the first three chapters have been mastered, the various sections may be taken in any order that the teacher finds most convenient. Students working alone may find it the best plan for a first reading—after studying the first three chapters—to deal only with the easier examples which begin each chapter, reserving the remaining exercises for a subsequent perusal of the book.

It is almost impossible to acknowledge each one of the many sources from which assistance has been obtained in preparing the book, but reference must be made gratefully to the well-known standard works of Prof. Unwin. Numerous examples have been taken from examination papers, particularly those of the Board of Education, and permission to do this has been given by the Controller of H.M. Stationery Office; these questions are recognised easily by the letters B.E. attached in each case.

I am indebted to Mr. C. P. Butler for several photographs reproduced in the following pages, and to the Council of the Institution of Mechanical Engineers for kind permission to use illustrations which appear in their publications.

The work of preparing the MSS. and of seeing the book through the press has been lightened a great deal by the kindly advice and experienced criticism received from Sir Richard Gregory and Mr. A. T. Simmons; and much trouble has been saved by the excellent way in which the printing has been done by Messrs. MacLehose & Co. Ltd.

FRANK CASTLE.

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CHAPTER I.

INTRODUCTORY.

Introductory. Although in some subjects, such as Freehand or Model Drawing, it is necessary to draw straight and curved lines without the aid of mathematical instruments, this is not the case in Machine Drawing. In making the drawings with which the reader of this book is concerned, such instruments are continually required, and it therefore becomes necessary at the outset to indicate the really necessary instruments, and also to explain how, when these have been obtained, they may be maintained in an efficient condition.

The few necessary instruments should be as far as possible of the best quality. A mistake too often made by the beginner is to substitute *quantity* for *quality*, the result taking the form of a nicely varnished box containing a number of instruments the majority of which are probably of little or no use. If to commence with it is impossible to purchase a good and fairly complete set, it will be better and cheaper for the student in the long run to obtain those instruments which are absolutely necessary and afterwards to add gradually to his stock.

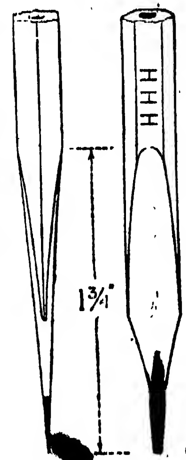


Fig. 1.

Pencils. Pencils should be neither too hard nor too soft; with the former, grooves are frequently made in the paper; while with the latter, it is a difficult matter to draw lines sufficiently fine for accurate work, as well as to preserve a uniform thickness of line throughout. In using soft pencils, also, a portion of the lead is easily rubbed off by the friction of the set squares and this is deposited on the surface of the paper in the form of dust, which tends to give the drawing a smeared and dirty appearance.

Probably the best pencil for general work will be found to be an HH or H, although in many cases an HHH or HHHH may be used with advantage. Such pencils are used most conveniently, when sharpened to a chisel point, along the edges of the T-square and the set squares. With this form of point (Fig. 1)

the edge is easily maintained by occasionally rubbing on a piece of *fine sand paper* or on a *smooth file*. A softer pencil may be used for sketching or for general purposes and may be sharpened to a round point (Fig. 2).

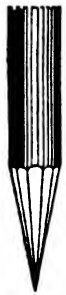


FIG. 2.

Compasses. One pair of 6-inch compasses will be required. The legs should be double-jointed, one terminating in a round point, or arranged to carry a needle, the other carrying a pencil or an inking-pen.

When a needle is used it should be as firm as possible. To effect this there are many different methods of fastening adopted, and of these that shown in Fig. 3 is very effective. The joint at **J** may be tightened or released by means of a small steel key, which consists simply of a small flat piece of steel with two pins or projections fitting the two small holes of the compass. The adjustment just referred to is frequently necessary. Thus, if the joint is too tight, some difficulty will be experienced in readily setting the compasses to a dimension; and if the joint is not sufficiently firm, an alteration may occur during the process of transferring a dimension from one place to another.

Dividers. Two forms of dividers are shown at **A** and **B** (Fig. 4). That at **B**, which is better

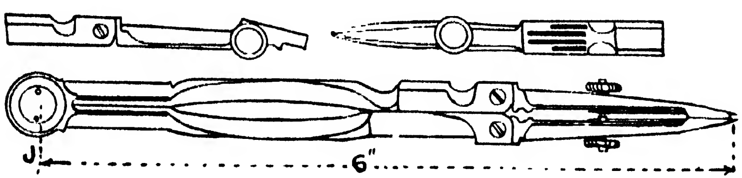


FIG. 3.—6" Compasses.

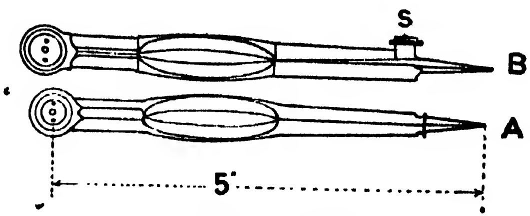


FIG. 4.—Dividers.

than that at **A**, is provided with a screw adjustment. In this case rotation of the screw **S** to the right or left enables the point to which it is attached to be opened or closed through a small distance.

Smaller compasses, pen and pencil, of about the size shown in Fig. 5, are necessary. Those most suitable have two joints, as shown at **J** and **K**. In the case of the pen compasses the knee joint at **K** is indispensable for good work.

Drawing pen. There are many varieties of drawing pens. One of the most useful is about 5″ or 6″ long (Fig. 6). The pen should be of good quality, and the handle is usually made of ivory or similar material.

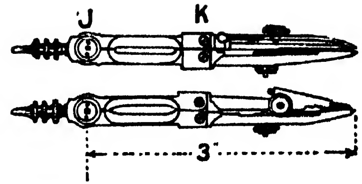


FIG. 5.—3″ Compasses.

Spring bows. Comparatively small dimensions, and especially small circles, are most readily drawn by what are known as *spring bows* (Fig. 7). These may be obtained either separately, or in a small box in which they may be kept when not in use.

Drawing board and T-square. The size of the drawing board obviously will depend on the size of paper to be used. A comparatively large sheet of paper will require a corresponding large board, and although a small drawing could be made on a large board it is far from convenient. Suitable sizes are known as *Imperial*, 30″ × 22″, and half these dimensions,

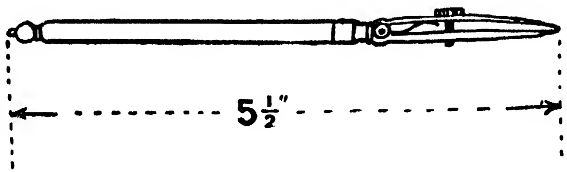


FIG. 6.—Drawing Pen.

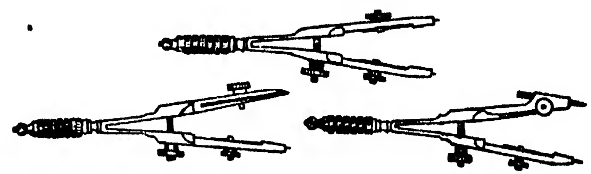


FIG. 7.—Spring Bows.

known as *Half-Imperial*. Though the former will be found useful sometimes, the latter is the more serviceable for the majority of purposes, and is suitable for most of the exercises given in this book.

The drawing board should be made of well-seasoned yellow pine and be free from knots. It should be provided with cross-bars or battens at the back to prevent the board from warping.

T-square. The blade AB of the T-square should be equal in length to the drawing board. The best material for it is mahogany with an ebony working edge. Such T-squares are somewhat expensive, and those made of pear wood are frequently used. The blade of the square should be firmly attached to the stock, but not sunk into it. The edge of the blade in time becomes uneven owing to the friction of the pen and pencil, and it becomes necessary to remove the blade from time to time for the purpose of

rectifying the edge by means of a plane. To ensure that, when replaced, the angle between the blade and the stock is unaltered, a couple of small wooden dowels, or pins, are usually inserted in the stock, as at **d d** (Fig. 8), and these fit tightly into holes in the blade.

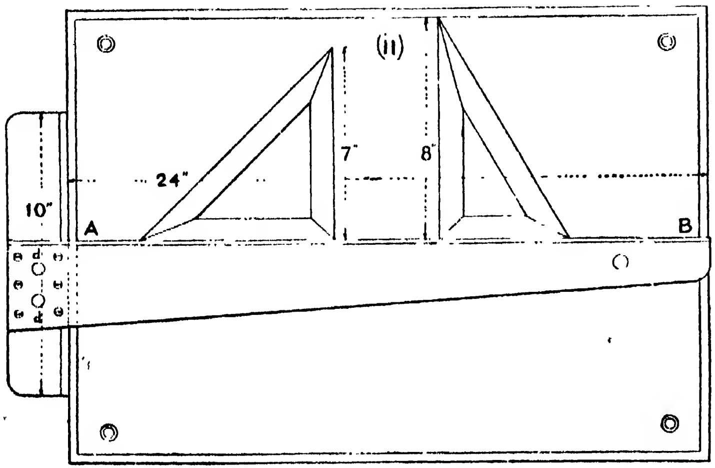


FIG. 8.—Drawing Board and Set Squares.

Drawing pins. The drawing paper used for exercise work and for working drawings is usually fastened to the drawing board by means of four drawing pins, one at each corner of the paper. By this method the paper may alter its position, or the heads of the drawing pins may obstruct the free motion of the **T**-square and the set squares. To avoid the latter objection, the corners may be secured by the use of a small quantity of sealing wax. The paper on which finished drawings are to be made, or on which a comparatively large amount of labour is to be spent, is often *stretched* upon the board. This stretching may be effected by turning down a portion about half an inch wide all round the paper; the surface of the paper is next damped with a sponge or cloth and the turned down portion is coated with thin glue, or gum; next, the glued edges are pressed carefully to the board, and when dry the paper presents a smooth surface.

Set squares. Two set squares, one 60°, the other 45°, of about the dimensions given in Fig. 8, are required. They may be obtained either of the form shown in Fig. 9 or (ii) (Fig. 8). The latter forms are known as framed set squares. Both kinds are made of a variety of materials, such as pear wood, sycamore, vulcanite, celluloid, etc. The framed set squares are easier to handle, and when made of pear wood or sycamore they are not so liable to alter their shape as those illustrated in Fig. 9.

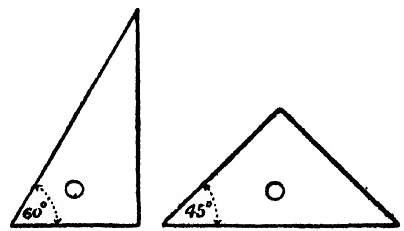


FIG. 9.—Set Squares.

French curves. What are called French curves are usually made use of to draw those curves for which the compasses are not applicable. Such curves are made of various materials, sizes, and shapes. French

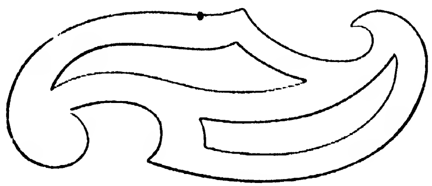


FIG. 10.—French Curve.

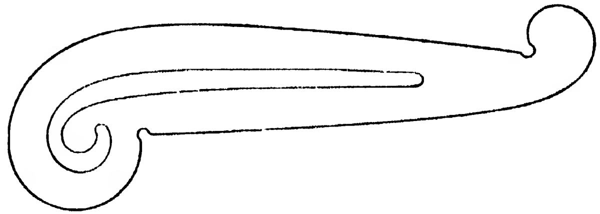


FIG. 11.—Scale-graded Curve.

curves made of pear wood or celluloid are, however, very convenient for use, and are obtainable in a variety of different forms. A useful form is shown in Fig. 10, but Harrison's scale-graded curves, one of which is shown in Fig. 11, are the best for all purposes.

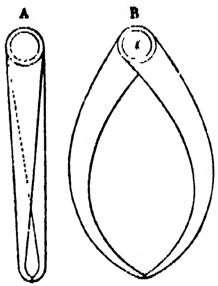


FIG. 12.—Inside and Outside Calipers.

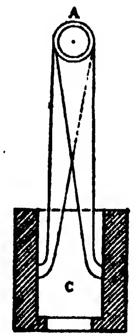


FIG. 13.

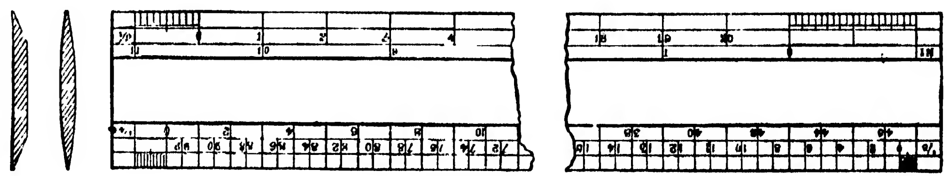


FIG. 14.

Calipers. To obtain the dimensions of round objects, such as cylinders, etc., two pairs of calipers, called *inside* and *outside* calipers, respectively, are necessary. The former are shown at **A** (Fig. 12), and are useful when the diameter or width of a cylindrical cavity has to be determined, as at **C** in Fig. 13. The *outside calipers*, **B**, (Fig. 12), are used to determine a dimension such as the diameter of a sphere. When the dimension has been obtained, the calipers may be applied to a rule or scale, and the magnitude of the dimension ascertained.

Scales. An ordinary two-feet rule or steel scale is used usually with the calipers. For machine drawing,

what is called an open-divided scale is useful. Such a scale is generally 8 or 12 inches long, and is made of boxwood. The section of such a scale may be either of the forms shown in the illustration (Fig. 14). With either of these forms the scale may be applied directly to the drawing, thus avoiding the use of instruments, a plan which enables the draughtsman readily and accurately to mark off a dimension on his drawing. The use of dividers or compasses on such a scale rapidly obliterates the divisions.

An open-divided scale usually shows scales of $\frac{1}{12}$, $\frac{1}{3}$, $\frac{3}{4}$, $\frac{3}{16}$ inches on one side, and $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{2}$, and 1 inch on the other.

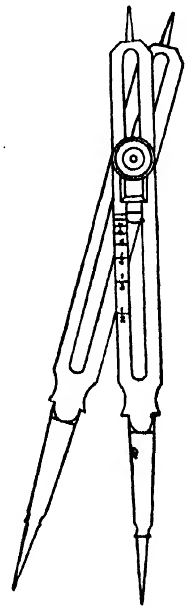


FIG. 15.—Proportional Compasses.

Printing. The title or description of a drawing may be either written or printed. If the former plan is employed, a clear bold handwriting should be used. Probably, the best results are obtained in printing when the letters are drawn freehand by a pen or brush; but, in the majority of cases, *stencilling apparatus* is used. *Stencil plates* are made of thin sheet copper or zinc, in which the various letters and figures are cut. Special printing ink and brushes are supplied with the apparatus. The setting of each letter or figure may be facilitated if a line is drawn on the stencil plate at the base of each letter, or figure.

Enlarging or reducing drawings. It is sometimes necessary to enlarge or to reduce a drawing. This process may be effected in several different ways. One method is to divide the surface of the paper on which the drawing is made into a large number of small squares, and by means of another sheet, on which the squares are larger or smaller than those on the first sheet, the drawing is enlarged or reduced as required.

Another method is to employ an instrument called a *pantograph*, which consists of a series of jointed levers carrying a tracing point and a pencil or pen. Starting from any convenient point, the tracing point is carried round the outline of the figure until the starting point is again reached. The pencil or pen in the meantime makes an enlarged or reduced copy of the figure. The pantograph is of great use to draughtsmen in map drawing, etc., but is not used much in machine drawing.

Proportional compasses. In dealing with the enlargement or reduction of machine drawings, proportional compasses may be used in preference to either of the two previous methods. The instrument consists of two limbs, having at each end rounded points as in a pair of dividers. The connection between the limbs is made by means of a pivot which can be placed at any position along the slot (Fig. 15).

The instrument is marked so that when the two points at one end are set to any given dimension, the distance between the points at the other will be $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, etc., of it.

Use of instruments. It is not only of the utmost importance to be able to make an accurate drawing, but also to work rapidly and easily so as to complete a drawing in a reasonable time. To effect this, facility in handling drawing instruments must be acquired, and this is possible only by constant practice.

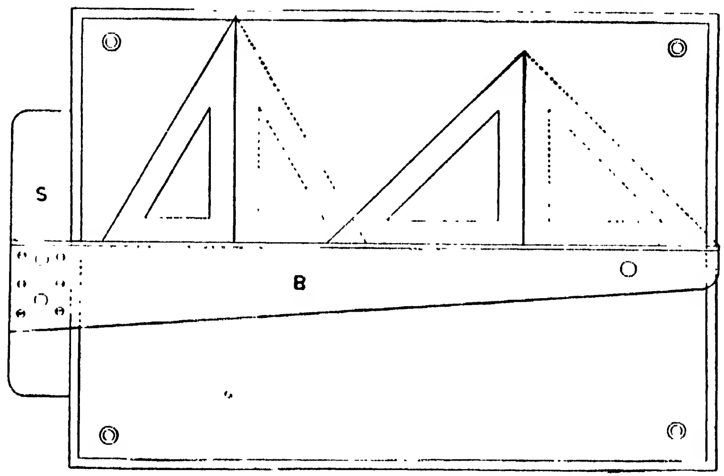


FIG. 16.—Tests of Right Angles of Set Squares.

To ensure that all instruments are maintained in an efficient condition, the following points should receive careful attention.

Use of T-square. The **T**-square should be placed on the board in the position shown in Fig. 16, and the stock, **S**, should be allowed only to slide along the left hand edge of the board; and it should *not* be used on the other edges. The left hand edge of the board and the stock, **S**, and blade, **B**, of the **T**-square should be tested by means of a straight edge, and if they are not straight they should be corrected by means of a *trying-plane* before being used.

Use of set squares. Set squares should be tested by placing them in the positions shown in Fig. 16, and drawing vertical lines. If, when the squares are reversed (as indicated by the dotted lines), the edges of the set squares do not agree with the lines already drawn, the edges should be adjusted until the lines drawn in the two positions coincide.

The angle of 45° may be tested by drawing an angle of 45°, and obtaining coincidence of the edge of the set square and the line already drawn when the set square is reversed.

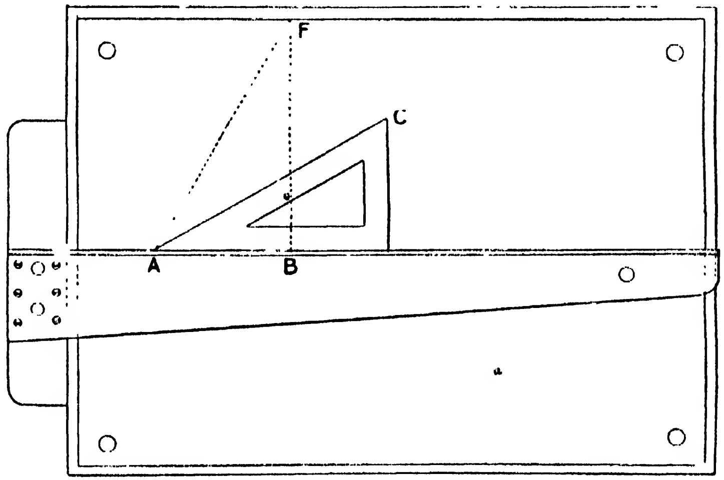


FIG. 17. Test of the Angles of a Set Square.

The 60° and 30° angles of the remaining set square may be tested by drawing an angle, **BAF** (Fig. 17), equal to 60° with the set square, and reversing the set square to obtain an angle of 30°. The edge of the T-square may be made to coincide with **AC**, and if the set square is inserted in the angle **CAF**, its edge should coincide with **AF**. If it does not, the necessary adjustment must be made.

A convenient method of drawing parallel and perpendicular lines is to slide one set square on the edge of another. Lines perpendicular to the parallel lines drawn in this manner are easily drawn by reversing

the set square (Fig. 18). These methods of drawing lines parallel and perpendicular to each other are of great use in practice.

Clinograph. One of the most useful instruments for drawing inclined lines and lines parallel to them is *Harrison's Clinograph* (Fig. 19). The edge **B** is made to slide along the edge of the **T**-square, and the

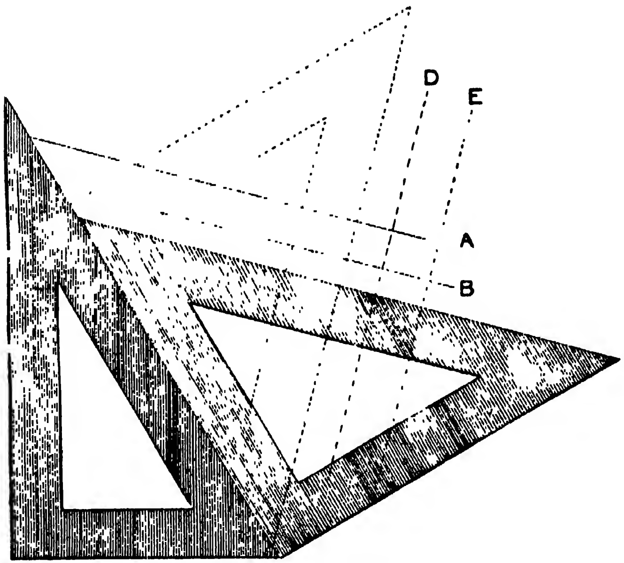


FIG. 18.—Parallel and Perpendicular Lines by Use of Set Squares.

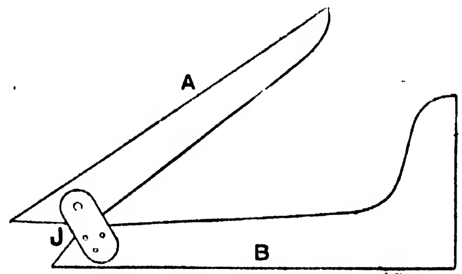


FIG. 19.—The Clinograph.

joint at **J** is sufficiently rigid to enable any number of parallel lines to be drawn. When the clinograph is reversed, a line at the same inclination to the horizon, but sloping in the opposite direction, can be drawn.

Setting a drawing pen. A drawing pen of good material will be serviceable usually for a long time before it is necessary to reset it. In some cases, however, the pen, after comparatively little use, requires

attention. When necessary, the two nibs of the pen should be brought into contact by means of the screw **S** (Fig. 20); then, holding the pen in a vertical position, the nibs are made of the same length by rubbing the end of the pen on an oilstone. The end of the pen should not be flat but carefully rounded. The rounding may be effected by moving the pen from side to side during the process of rubbing as indicated by the dotted lines in Fig. 20. The nibs are unscrewed afterwards and each worked up to a good edge, which should be rounded by slightly rocking the pen between the fingers during the rubbing. The inclination at which the pen is held should increase as the rubbing proceeds, and care must be taken not to make a sharp edge; to ensure this the edge should be examined at frequent intervals. When finished, each nib should have the same appearance and should, when looked at end-on, show a small spot of light. After carefully wiping the nibs to get rid of all traces of oil the pen should be tried by using it to draw thick and thin lines. If the pen is too sharp it may be put right by making a few strokes with it on cartridge paper.

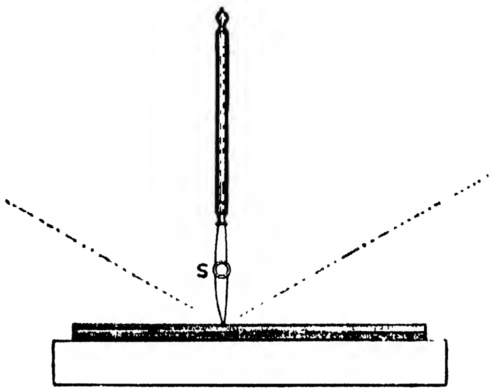


FIG. 20.—Setting a Drawing Pen.

The compass pen is adjusted in a similar manner.

The inside surfaces of the nibs must not be sharpened. If a slight burr is formed during sharpening, it may be removed by using a small piece of smooth emery paper, or better by a thin slip of oilstone.

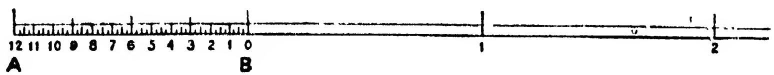


FIG. 21.

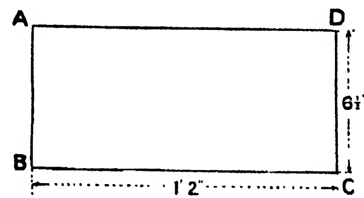


FIG. 22.

Drawing to scale. The student who has used cycling or other maps is already familiar with the fact that the distance between two places on a map gives no information as to the actual distance between the

places themselves unless the scale to which the map is drawn is specified. Thus, the distance between two places may be known to be 30 miles; if on the map this distance is represented by a length of 3″, then the distance between two other towns one inch apart on the same map would be 10 miles. Such a map would be said to be drawn to a *scale of* 10 *miles to an inch*. In a similar manner, if on a drawing a distance of 4 inches represents 1 foot, the scale would be $4'' = 1'$ or $\frac{1}{3}$ full size. Although scales can be obtained cheaply it is often necessary to be able to make one. Such a scale should be as accurate as possible and be made either on thick cartridge paper or on thin cardboard. Scales should be kept flat and without creases for future use.

Example. Make a scale of $4'' = 1'$ or $\frac{1}{3}$ full size.

Draw two lines about an eighth or three sixteenths of an inch apart. Measure off a length **AB** $= 4''$ (Fig. 21); this length represents 1 ft. or 12 in. and may be divided into 12 equal parts, and these may be subdivided further into half or quarter inches. Finally, as many divisions denoting feet as may be necessary are marked off from left to right, and the scale is complete.

Dimensions. The dimensions of an object are usually indicated by dotted lines; the small arrowheads at the end of the lines should be put in neatly and should join close up to the lines from which the dimensions are taken. In Fig. 22 the length of the rectangle is 1 foot 2 inches, and this is expressed by 1′ 2″; the width is $6\frac{1}{2}$ inches and is denoted by $6\frac{1}{2}''$.

Angular measurements. Abbreviations are used also to denote angular measurements. Thus, an angle of thirty degrees, twenty minutes, ten seconds, is written 30° 20′ 10″. To understand clearly what such a measurement implies, the beginner may consider the motion of a pointer, such as a movable radius of a circle, or the minute hand of a clock, capable of moving about an axis or centre **A** (Fig. 23). If such a line, as **AC**, moves in the opposite direction to the hands of a clock, then the amount of rotation of the line may be expressed by the angle **DAC**. This angle may be indicated either by the number of degrees or radians in it.

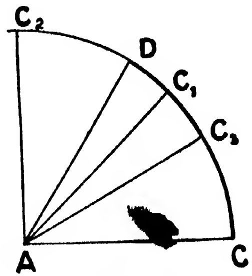


Fig. 23.

Measurement in degrees. Assuming the circumference of a circle to be divided into 360 equal parts, then any two consecutive points joined to the centre will enclose an angle of *one degree*. A line **AC**$_2$ (Fig. 23) perpendicular to **AC** will be one-fourth part of 360° or 90°.

If a point C_3 be taken, such that the arc CC_3 is $\frac{1}{6}$th a semicircle, then the angle $CAC_3 = 30°$. Again, if C_1 is the middle point of the arc CC_2, then C_1 joined to A, will denote an angle of 45°.

Radian measure. The radian measure of an angle denotes the ratio $\frac{\text{arc}}{\text{radius}}$. The unit of measurement is obtained by taking an arc CD (Fig. 23) equal to the radius AC; by joining D to A, the angle DAC—equal to one radian $= 57°·3$ approximately—is obtained.

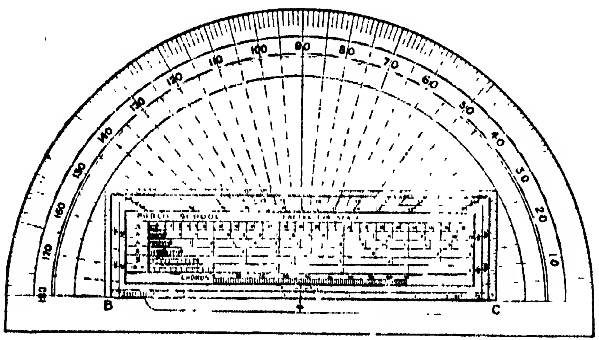


FIG. 24.—Protractors.

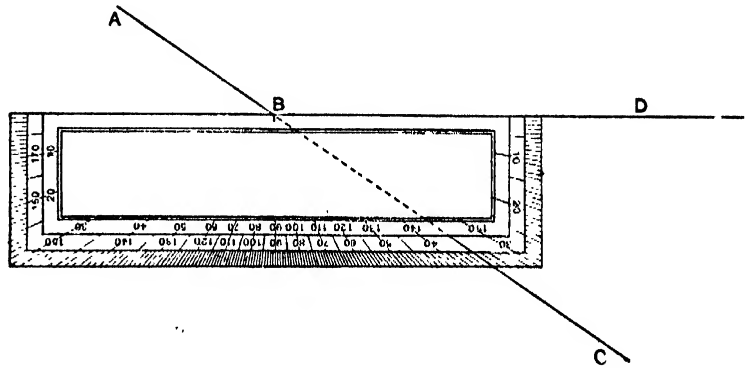


FIG. 25.—Use of Protractor.

Protractor. The angles 30°, 45°, 60°, and 90°, may be set out by means of set squares, and multiples and submultiples of these may be obtained by bisection and by the process of adding one angle to another. But any angle (including those referred to) can be set out at once by means of a *protractor*. Such an instrument is usually made either in the form of a circle, a semicircle, or rectangle. The two latter are shown in Fig. 24.

Use of protractor. *At the point* B *in the line*, AC, *to make an angle of* 35° (Fig. 25). Place the mark on the protractor immediately below the division marked 90° coincident with the point B and

the division corresponding to 35° on the line **AC**. Using the edge of the protractor as a ruler, draw the line **BD**. Then **DBC** is an angle of 35° required.

Conversely, to measure the magnitude of a given angle: put the mark on the protractor at the vertex of the angle and the edge of the protractor coincident with one of the lines forming the angle; then the magnitude of the angle can be read off at the point where the remaining line crosses the divided edge of the protractor.

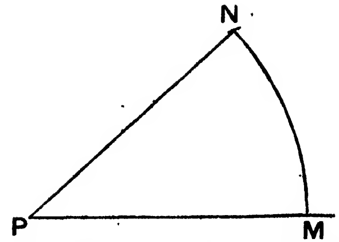


Fig. 26.—Use of a Scale of Chords.

Table of chords. Ordinary protractors are rarely trustworthy, and it frequently happens that expensive instruments are more or less inaccurate. Probably the most accurate method of setting out a required angle is by means of a *table of chords*.

Example. To set out an angle of 43°.

On any convenient scale make **PM** equal to 10 units (Fig 26). With **P** as centre and **PM** as radius, describe an arc of a circle. In Table IV. (p. 243), we find corresponding to 43° the number 0·733, and multiplying this by 10 we obtain 7·33. Hence, with centre **M** and radius 7·33, describe an arc intersecting the former arc in **N**. Join **N** to **P**, then **MPN** is an angle of 43°.

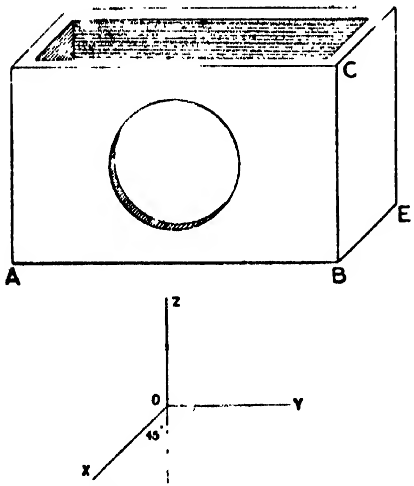


Fig. 27.—Metric Projection.

Projection. As an easy example of projection we may consider how the representation of a simple box such as that shown in Fig. 27 may be made. The dimensions are as follows: Length, 2 ft. 6 in.; width, 1 ft. 3 in.; depth, 1 ft. 6 in.; thickness, 2 in. A hole 12 in. diameter is made in one of the longer sides. These dimensions, as indicated in Fig. [illegible] would be 2′ 6″, 1′ 3″, 1′ 6″, respectively.

As the representation of such an object may be made in several different ways it may be desirable to ascertain briefly the relative advantages and disadvantages of these methods of representation.

A *photograph* of the box would show the relative length, width,

depth, and thickness, in one view, the disadvantage being that it would be impossible to apply a scale to the photograph to ascertain the actual dimension of any part.

The assumption is made that the box is so constructed that a photograph of it is obtainable. When this is not the case the photographic method obviously is inapplicable.

Perspective projection. A representation of the box might be made in perspective projection. Such a projection would, as in the preceding case, indicate the relative dimensions of length, width, and depth, and would correspond in many respects to the photograph. The objections as to measurement apply also to this method.

Another method in which the three dimensions may not only be shown in one view but in addition may be measured by means of a scale is known as *metric projection*.

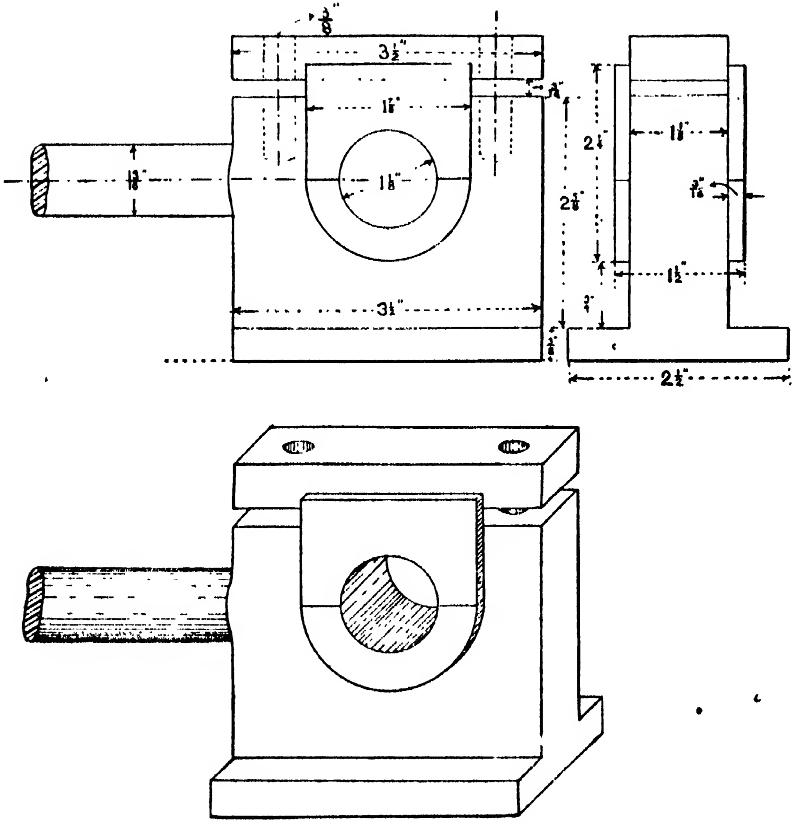


FIG. 28.—Metric Projection of a Cross-head.

Metric projection. For the purpose of representing the box in metric projection three axes **Ox**, **Oy**, and **Oz**, as in Fig. 27, are drawn. All dimensions along **Oy** and **Oz** are made full size. The same scale could be used for dimensions in the direction **Ox**, but it will be found that such a method produces a distorted figure, and it is much better to reduce the dimensions in the direction of **Ox**. A useful and easily made scale drawing is obtained by setting off all dimensions in the

direction of **Oy** or **Oz** to true size and the dimensions in the direction **Ox** to half size. Thus, in Fig. 27, **AB** and **BC** are made 2′ 6″ and 1′ 6″ respectively, but **BE** is made $\frac{1}{2} \times 1'\ 3''$ or $7\frac{1}{2}''$ to the same scale. Fig. 28 shows a small crosshead drawn half size in metric projection.

Orthographic projection. The usual method adopted by engineers and others to represent solid objects, such as occur in machines and machine details, is called *orthographic projection.* Unless the object is of the simplest form, two or more views properly projected from each other are required. Various names are given to these views, such as *elevation, plan, section, sectional plan, end view,* and *sectional elevation.* Using as a model an empty rectangular box (such as a cigar box without a lid), it will be an easy matter to verify the projections shown in Fig. 29. These projections should be drawn carefully to scale as follows:

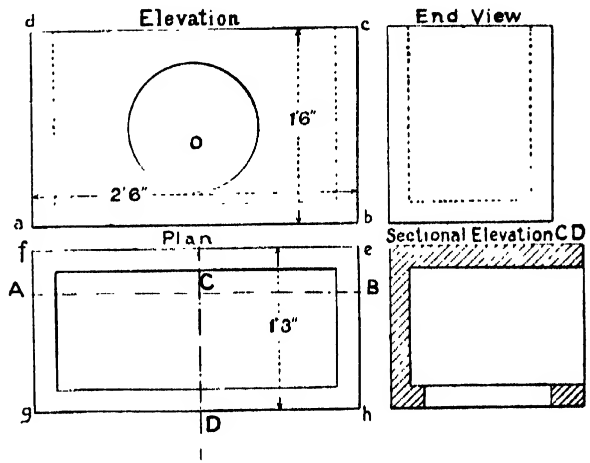


FIG. 29.—Orthographic Projection.

Commence by drawing an indefinite line and marking off to scale the two points **a** and **b** (Fig. 29) equal to 2′ 6″. Draw vertical lines at **a** and **b**, making **bc** equal to 1′ 6″, and draw **cd** parallel to **ab**. Obtain **O**, the centre of the face **abcd**. With **O** as centre and radius 6″, describe a circle. Then the elevation of the box is completed by drawing dotted lines parallel to **ab**, **bc**, and **ad**, and at a distance of 2″ from them. These lines represent the thickness of the box. By the set square project the edges **bc** and **ad**. Draw a line **ef** and make **eh** = 1′ 3″; also draw **hg** parallel to **ef**. Mark off from **ef** and **eh** equal distances of 2″, and draw the inner rectangle; then the two rectangles shown represent the plan of the box.

The end view is projected from the elevation and the width obtained from the plan.

Sections and sectioning. In the drawings of machines and machine details, the elevation, plan, and end view, are not always sufficient to show clearly the whole arrangement, particularly the internal arrangement. *Dotted lines* may be used for the purpose, but these are in many cases difficult to follow. The objects are assumed, consequently, to be cut by *section planes* in such a manner that the arrangement of the

various parts can be clearly seen. If sections of the box along lines such as **AB** and **CD** be assumed, then views corresponding to *sectional elevations* are obtained, as in Fig. 29. The parts cut by a plane of section are indicated by one of the following methods. The first plan is to draw diagonal lines at or about 45°, either freehand or more accurately with the 45° set square. Such section lines, however, can be put in much more rapidly with a brush, using a suitable colour for the purpose.

A flat wash of colour applied to those parts which are in section may also be used for the same purpose.

In each of the colour methods there is the distinct advantage that the materials of which the parts are made can be seen at once from the drawing.

The colours used by engineers and indicated in the following table may be obtained either in the form of *dry* or *moist* colours. Dry colours are obtainable in *cakes* or *half-cakes* and are rubbed down with a small quantity of water in a suitable dish or saucer. Moist colours are obtainable in *porcelain pans* or in *soft metal tubes* and only require the addition of water to render them fit for use. The conventional colours used by engineers for machine drawings are given in the following table:

MATERIAL.	COLOUR.
Cast iron,	Payne's grey or neutral tint.
Wrought iron,	Prussian blue.
Steel,	Purple (may be obtained by mixing prussian blue and crimson lake).
Brass,	Gamboge or Indian Lake.
Brickwork,	Crimson Lake.
Wood,	Burnt Sienna.
Stone,	Bistre.
Earth,	Sepia.

Conventional arrangements. Bolts, nuts, screws, rivets, and pins, which occur along a plane of section, are not usually shown in section except when they are cut by a section plane in a direction at right angles to their length, *i.e.* in a transverse direction.

Sectioning. When it is inconvenient or impossible to denote the materials used in the construction of a machine detail by suitable colours, the materials may be indicated by suitable alterations in the sectioning

adopted. A list of the materials in common use, together with the form of sectioning which may be used to designate them, is given in Fig. 30. In the majority of cases, however, the nature of the material can be easily inferred from the drawing, or, if not, a description may be written on it.

Saucers and brushes. The difficulty with regard to sectioning is removed by the use of suitable colours to designate the various materials. A list of colours is given on p. 16. Porcelain dishes or saucers, supplied in the form of a "nest" consisting of four or more dishes fitting one above the other (Fig. 31), are usually used to hold the colours.

The brushes may be either of camel hair or sable. Sable, although more expensive, is much to be preferred to camel hair. When filled with colour the brush should terminate in a fine point. (Fig. 32.)

Inking in. A good black ink is obtained by rubbing a stick of Chinese or Indian ink in a little water. The colour may be tested from time to time as the rubbing proceeds by dipping a brush in the ink and smearing it on a piece of white paper. There are many kinds of *fluid* (Chinese and Indian) inks to be

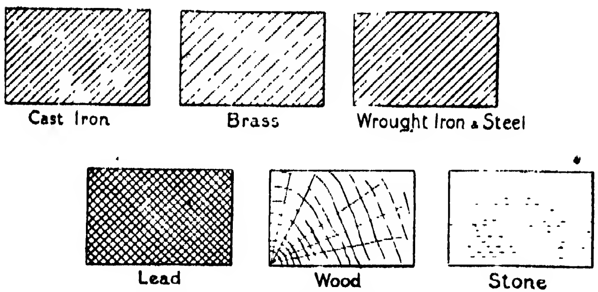


FIG. 30.—Conventional Sectioning.

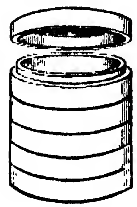


FIG. 31.

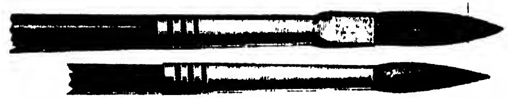


FIG. 32.

obtained, but in many cases the lines made by these are, when dry, of a dark brown colour instead of being black. But by the process of rubbing a deep black ink may be obtained, the lines made by which are, when dry, of a glossy appearance.

As a rule it will be found to be easier to draw straight lines touching curves than to perform the converse operation; hence, when inking in, it is advisable to commence by inserting all the circles and arcs

of circles in the drawing. When this has been done the horizontal lines may be inserted by using the T-square, and the remaining lines by means of the set squares. The drawing is now complete, with the possible exception of perhaps a little cleaning by means of a soft piece of india-rubber.

Sections of bars. In the drawings of machines and machine details it often happens that it is only necessary to show a portion of the length of a bar, and thus "breaks" occur. These breaks may be used with little trouble as a means of indicating at a glance the form of the cross-section. The method applied to some of the standard forms kept in stock by iron merchants is shown in Fig. 33. Thus, at (a), the section indicates a round bar; at (b), a hollow round bar; at (c), a square bar; at (d), a rectangular or flat bar; at (e), an I-section; at (f), an angle; and at (g), one of the useful conventional methods of indicating the break in a piece of timber.

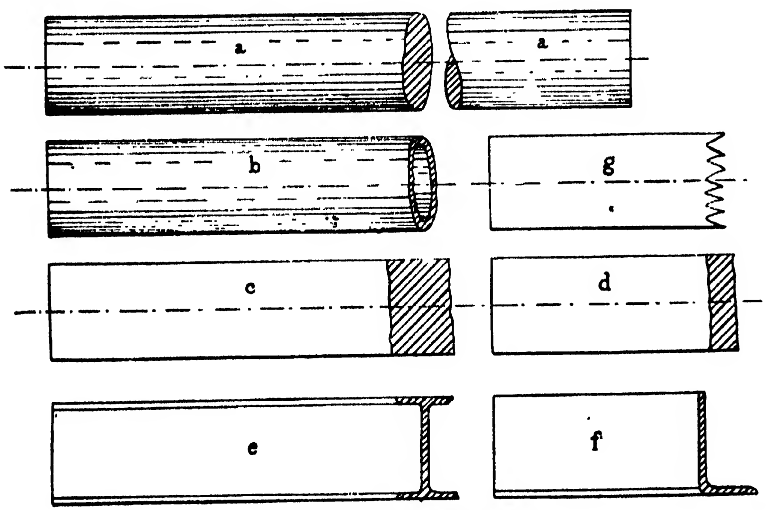


FIG. 33.—Sections of Bars.

Standard forms. In Fig. 34 are shown some cross-sections of the forms of bars usually kept in stock by iron merchants and others.

Working drawings. A working drawing usually need not be inked in and coloured. A common method is to make a clear and accurate drawing in *pencil,* and from this to make a *tracing* in ink. The tracing can then be used to obtain as many copies as are required in the form of *prints.* Such prints are either what are called *blue-prints, i.e.* white lines on a blue ground; or black and white, *i.e.* black or dark brown on a white ground.

The printing frame necessary to obtain such prints simply consists of a frame in which the tracing can be placed close to a transparent sheet of glass. Behind the tracing is placed a sheet of prepared paper, and behind this a strip of felt or cloth to prevent light from entering except at the front. After exposure to the light the prepared paper is taken out and washed in water, and when dry is fit for use. In blue prints any sections

that occur may be indicated by diagonal section lines. The same process may also be adopted in the "black and white." Or, the outline only need be shown, the colours indicating any sections being put on the print.

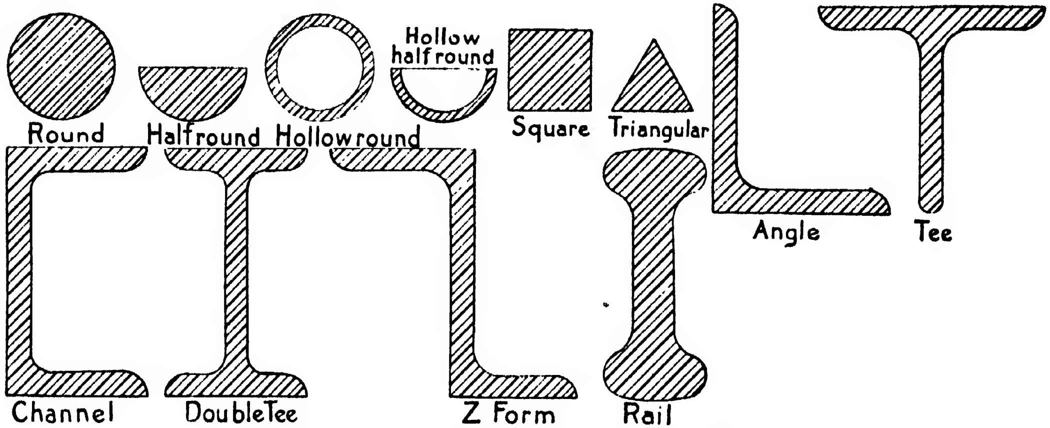


FIG. 34.—Cross-sections of Standard Forms of Bars.

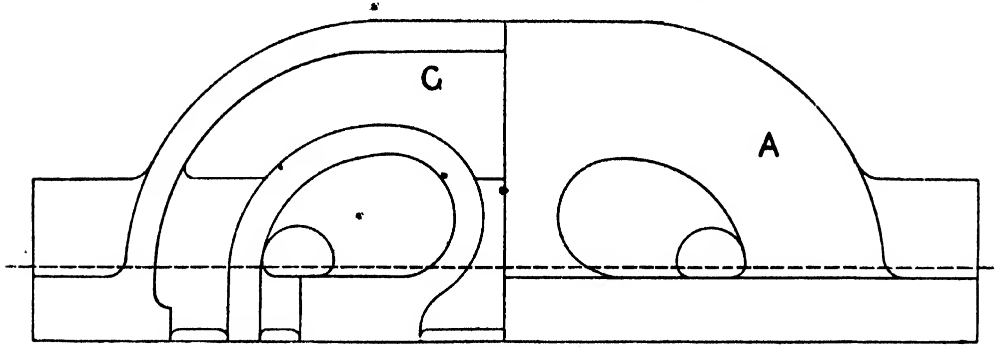


FIG. 35.

Tracings. In making a tracing, what is called *tracing paper* or *tracing cloth* is used. The paper or cloth is placed over the drawing and fastened to the drawing board by means of drawing pins. As the lines show clearly through the transparent paper, a copy can be made in ink. Care must be taken that the lines are not too thin, and also that they are throughout uniform in thickness. Any of the exercises in the following chapters may be used for this purpose.

Example. Make a tracing of the diagram shown in Fig. 35.

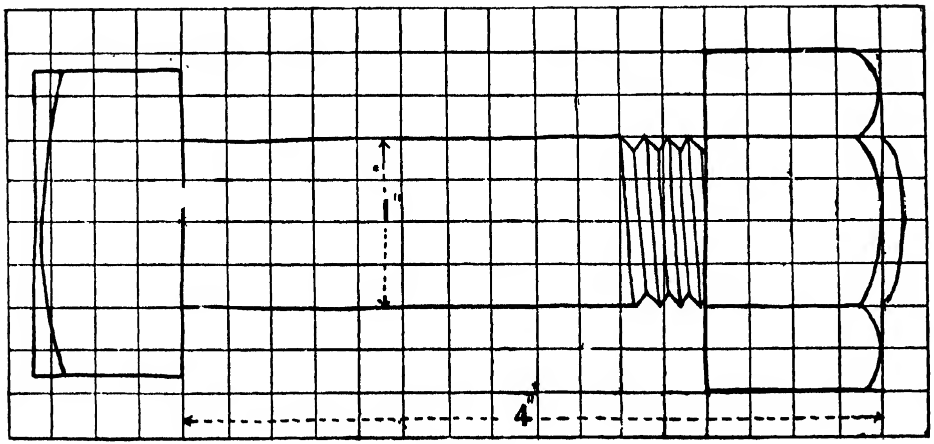


FIG. 36.

Hand sketching. It is of the utmost importance to a student to be able to make hand sketches of machine details. The various parts should be inserted in fairly good proportion, and, in addition, important dimensions should be indicated. For the purpose of such sketches, paper ruled into $\frac{1}{4}$-inch squares is very suitable; the lines forming the squares are usually of a faint grey colour and do not interfere with the lines of the sketch. Sketches may be made readily to full, half, or quarter size. Figs. 36 and 37 show two sketches; the former is full size and the latter is $\frac{1}{4}$-full size.

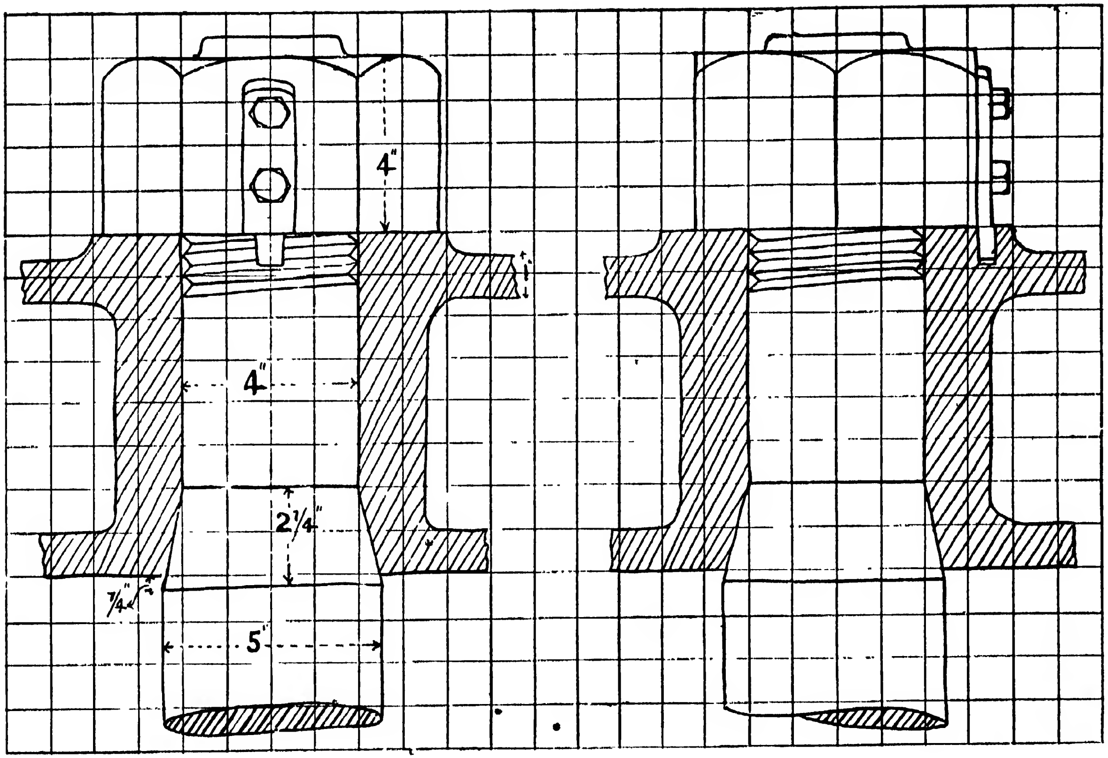


FIG. 37.

Simple geometrical constructions. The following simple but important geometrical constructions should be noted carefully:

To bisect a line **AB** *by a line perpendicular to it.* Let **AB** be the given line. With **A** and **B** as centres, and any convenient radius, describe arcs intersecting at **C** and **D** (Fig. 38). The line **CD**, joining the points of intersection, is perpendicular to and bisects **AB**.

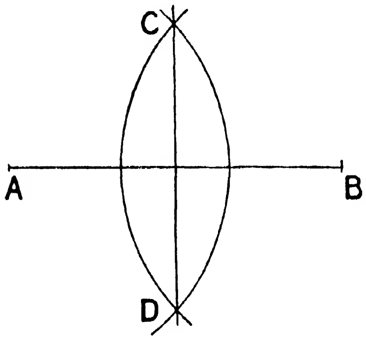


FIG. 38.—Bisection of a line.

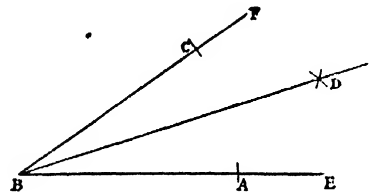


FIG. 39.—To bisect an angle.

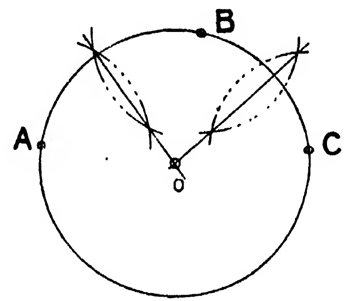


FIG. 40.—Circle passing through three points.

To bisect a given angle. Let **EBF** (Fig. 39) be the given angle. With **B** as centre, and any convenient length, mark off equal distances **BA** and **BC**. With centres **A** and **C**, and any convenient radius, describe arcs intersecting in a point **D**. Join **D** to **B**. Then **DB** is the required bisector.

To describe a circle passing through three given points. Let **A**, **B**, and **C** be the three given points. With **A** and **B**, and **B** and **C**, as centres, describe intersecting arcs (Fig. 40). Join the points of intersection, and produce the lines to intersect at a point **O**. Then **O** is the centre required.

To find the centre of a circle or circular arc. This exercise is only a repetition of the preceding one. Take three points in the circle or circular arc, and, as in the preceding case, describe intersecting arcs

Join the points of intersection, and produce until they intersect at a point. This point of intersection is the centre required.

To describe a circle of given radius touching a given straight line and a given circle. Let **AB** be the given line and **C** the given circle (Fig. 41). As a simple example we may assume the radius of the given circle to be 1″. It is obvious that as the circle has to touch the line **AB**, its centre will lie at some point on a line **EF** parallel to **AB** and 1″ from it. Similarly, the centre will lie in an arc of a

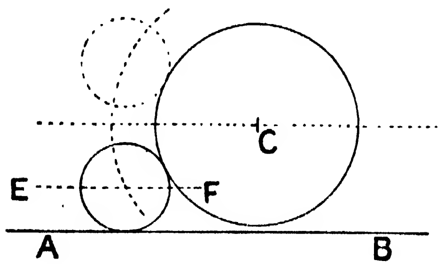


Fig. 41.

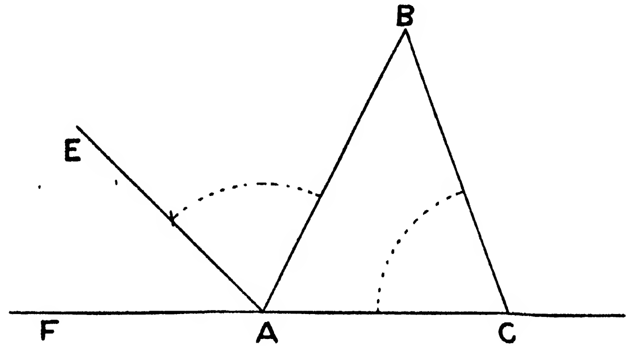


Fig. 42.

circle of centre **C** and at a distance of 1″ from the circumference. The intersection of the arc with the line **EF** is the centre required.

The three angles of a triangle are together equal to two right angles. This important geometrical proposition may be verified by several methods. An experimental verification is as follows:

Draw any triangle **ABC** (Fig. 42). Denote the three angles by **A**, **B**, and **C**; add the angle **C** to the angle **A**, then an angle such as **CAE** is obtained; finally, add the angle **B**. The result is the angle **CAF**, *i.e.* the line **CA** produced.

Regular polygon. When the sides or edges of a polygon are equal in length, and all the angles are

equal, the figure is called a *regular polygon.* The following table gives the number of sides in the more important regular polygons. The table should be committed to memory:

3 sides,	-	equilateral triangle.	7 sides,	-	heptagon.
4 ,,	-	square.	8 ,,	-	octagon.
5 ,,	-	pentagon.	9 ,,	-	nonagon.
6 ,,	-	hexagon.	10 ,,	-	decagon.

To construct a regular polygon, given the length of one of its sides.

Equilateral triangle. Let **AB** denote the length of the given side (Fig. 43). Then an equilateral triangle may be obtained by using the 60° set square. Or, with **A** as centre, and radius **AB**, describe an arc; similarly, with **B** as centre and the same radius, describe another arc, intersecting the former in **C**; join **C** to **A** and **B**; then **BAC** is an equilateral triangle.

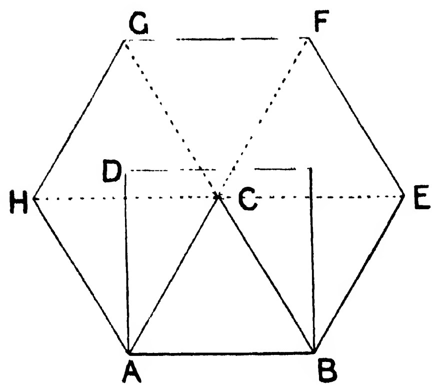


FIG. 43.

Square. A square may be constructed by making **AD** perpendicular to and equal to **AB**, and drawing lines parallel to **AD** and **AB** respectively.

Hexagon. Draw the line **AH** with the 60° set square and make **AH** = **AB**; reverse the set square and draw **HG**, making **HG** = **AH**. This procedure forms one half of the hexagon. The polygon is completed by using the **T** and the set square.

Octagon. An octagon may be constructed similarly by using the 45° set square.

If all the angular points, **ABE**..., of a regular polygon be joined to the centre **C** (Fig. 43), the number of triangles formed is obviously equal to the number of sides in the figure. Since the sum of all the angles formed at the centre is 4 right angles, or 360°, it follows that to obtain the magnitude of the angle in a regular polygon we may use the following rule: *From twice the number of sides in the figure, subtract four, multiply the remainder by 90°, and finally divide by the number of sides in the figure.*

Example. Find the angle between any two sides in a regular (*a*) hexagon, (*b*) pentagon.

(*a*) Here double the number of sides is 12.

Also $$\frac{(12-4)90}{6} = 120^\circ.$$

(*b*) $$\frac{(10-4)90^\circ}{5} = 108^\circ.$$

Another method which depends only on construction is as follows:

With **A** as centre and radius **AB** describe a semicircle; divide the semicircle into the same number of equal parts as the number of sides in the figure, and number these 1, 2, 3, ... ; join **A** to division 2. Then **BA** and **AE** are two sides of the required figure (Fig. 44).

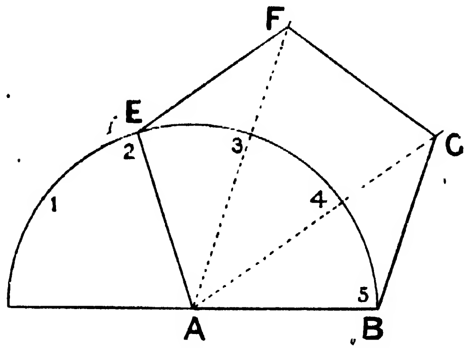


FIG. 44.—Construction of a Regular Pentagon.

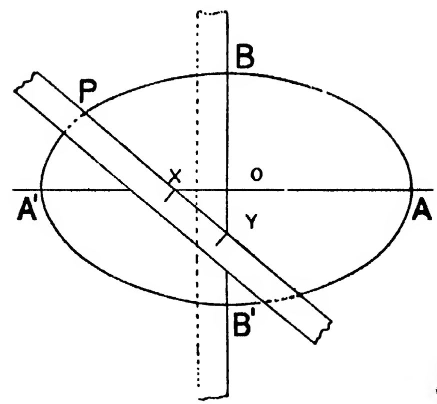


FIG. 45.—Construction of an Ellipse.

Example. Construct a regular pentagon, length of side $1\frac{1}{2}''$.

Make **AB** (Fig. 44) equal to $1\frac{1}{2}''$ and with **A** as centre and **AB** as radius describe a semicircle. Divide the semicircle into five equal parts. Join **A** to 2; then **EA, AB,** are two sides of the required

pentagon. Join A to 3 and to 4 and produce the lines; the polygon is completed by making EF, FG equal to AB.

Ellipse. If O is the centre of an ellipse (Fig. 45), the lines AA′, BB′ at right angles to each other and passing through O are the *axes of the ellipse.* The longer axis AA′ is called the *major axis,* and the shorter BB′ the *minor axis.*

To obtain points on the curve we may use a straight strip of paper in the following way. On the strip mark off lengths YP equal to OA′, and XP equal to OB. If the points X and Y be made to move

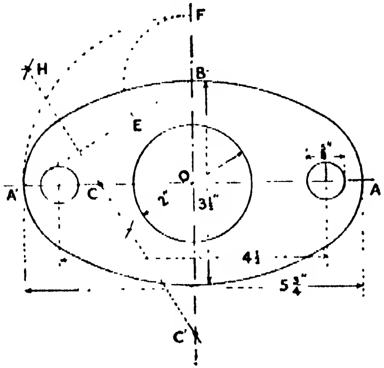


Fig. 46.

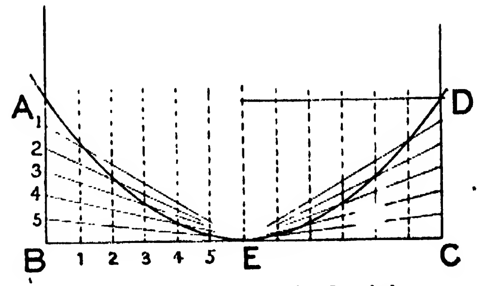


Fig. 47.—Construction of a Parabola.

along the lines AA′ and BB′, and the successive positions of P are marked, a series of points on the curve are obtained. The curve may be put in neatly by freehand; or, if necessary, the points may be transferred to a piece of celluloid, thin wood, or zinc, and a template may be made by cutting out the figure as carefully as possible, finishing the edge by a smooth file or a piece of glass paper. In making such a template only one quarter or one half the curve is necessary.

An ellipse, or some approximation to it, is usually the form adopted for small glands, stuffing boxes, the flanges of pipes and other cases where two bolts are used. An approximation is as follows:—Join A′ to B, set off OF = OA′, and BE = BF (Fig. 46). The line HC′, bisecting A′E at right angles, determines the two centres, C and C′; C being the centre for the circular arc forming one end of the ellipse, while C′ is the centre for the upper part of the curve.

Parabola. A simple method of drawing a portion of a parabola—a modification of which may be used to draw an ellipse—is to obtain a series of points on the curve by using either a rectangle or a parallelogram.

Thus, to inscribe a parabola in the rectangle **ABCD** (Fig. 47) we may proceed as follows. Bisect the base **BC** at **E**; divide **BE** and **BA** each into the same number of equal parts; through the points 1, 2, ... 5 draw lines parallel to **BA**; join the points 1, 2, 3, 4, 5, on **AB**, to **E**; the points of intersection of these lines with the lines already drawn give a series of points on the curve required.

The portion of the curve to the right of the point **E** is obtained in a similar manner. The curve may be drawn either freehand or by means of a French curve.

EXERCISES I.

1. Draw scales of (*a*) $\frac{3}{4}''$ to $1'$, and (*b*) $1\frac{1}{2}''$ to $1'$, each to be long enough to measure 3 ft.; (*a*) is to read to tenths of an inch, and (*b*) to eighths of an inch.

2. Set out an angle of 43° 20′. Bisect the angle and draw two circles touching each other and both sides of the angle. The diameter of the smaller circle is to be 1″.

3. The base of a triangle is 3·58″ long, and the angles adjacent to it are 45° and 63° 40′ respectively. Draw the triangle and measure the two sides and remaining angle. State the magnitude of each of the angles in radians. Draw a circle passing through the angular points of the triangle.

4. Construct a regular heptagon of side 2″.

5. Draw an ellipse with axes 4″ and 2″ respectively.

6. Inscribe a parabola in a rectangle of sides 3″ and 1″ respectively.

7. Draw a line 7″ long and divide it into nine equal parts. Construct a triangle with sides equal to 2, 3, and 4 of these parts. Measure the angles of the triangle and find their sum. Draw a circle to touch the three sides of the triangle.

8. Sketch, full size, the following cross-sections: (i) angle iron $2'' \times 3'' \times \frac{3}{8}''$, (ii) channel iron $6'' \times 3'' \times \frac{3}{8}''$, (iii) tee iron $3'' \times 3'' \times \frac{3}{8}''$, (iv) double tee or rolled steel joist, flanges $5'' \times 0{\cdot}6''$, web $0{\cdot}6''$, depth $12''$.

CHAPTER II.

RIVETS AND RIVETED JOINTS.

Joints. The joint between two plates or between the parts of a machine may be made by welding or a similar process, by rivets, or by bolts. The process of *riveting* furnishes a rigid fastening which is usually cheaper and simpler than that obtained by using bolts. Steam and water joints in boilers, in cylinders, in cisterns, etc., may be made in this manner. A riveted joint when once made can only be disconnected by cutting off the heads of he rivets, thus destroying the fastening. Those joints which require to be disconnected at intervals for renewals or repairs are made usually by bolts.

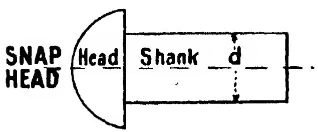


FIG. 48.—Rivets.

Rivets. A rivet is a round bar of iron, steel, or other metal, one end usually being enlarged to form what is called the *head* of the rivet (Fig. 48). The smaller portion is called the shank, or diameter, of the rivet. The opposite end to the head is called the point of the rivet.

Riveting. The two general methods of riveting are known as (a) *hand*, (b) *machine* riveting. In *hand riveting* the point of the rivet is made red hot in a clear charcoal fire or oil furnace; the rivet is then placed in suitable holes in the plates to be joined, with a sufficient length of metal projecting to form the remaining head. The head of the rivet is held in place by means of a heavy weight, whilst the second head is formed by two riveters. This second head may be made conical. The rivets are more easily worked in a red hot state than when cold, the contraction due to cooling tends, moreover, to draw the plates closer together, and thus to make a better joint than would otherwise be the case.

In machine riveting the head of the rivet is held firmly in one jaw of a hydraulic or pneumatic machine whilst the other forms the remaining head. In this process great pressure is available; the total pressure is

usually about 80 tons on each rivet of 1 in. diameter, and about 60 tons on each $\frac{7}{8}$ in. rivet. In boilers, all rivets, wherever possible, are closed in this manner by hydraulic machinery, hand riveting only being allowed where it is impossible to apply machinery.

Lap joint. In the *lap joint* the two plates overlap each other and are secured by one or more rows of rivets.

Butt joint. The name *butt joint* is given to the joint in which the two plates meet or butt against each other, and the joint is made by using one or two cover plates or *butt straps*.

Pitch. The pitch of the rivets is the distance from the centre of one rivet to the centre of the next. This distance will be denoted in this book by the letter **p**.

In a single riveted lap joint there is one row or line of rows, and two rows in a double riveted joint (Fig. 49).

Margin. The term *margin* is applied to the distance from the edge of the rivet hole to the edge of the plate. The minimum distance is the diameter of the rivet. The margin is usually a little greater than this, and the distance from the centre of the rivet to the edge of the plate is consequently a little greater than one and a half times the diameter of the rivet.

Forms of rivet heads. Some forms of rivet

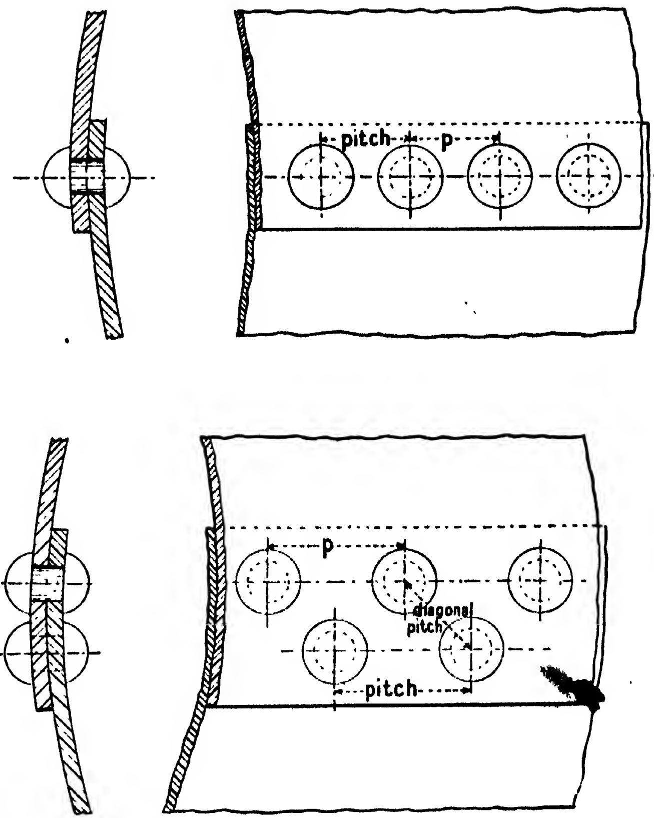


FIG. 49.—Single and Double Riveted Lap Joints.

heads are shown in Fig. 50, and are known as (**I**) a *snap head*; (**II**) a *conical and pan head*; (**III**) a *countersunk head*.

Snap head. This is the form of rivet head in general use. The proportions adopted are those shown in Fig. 50, the unit being **d**, the diameter of the rivet. Thus, the *spread*, or diameter, of the rivet head is 1·7**d** and the thickness from 0·6**d** to 0·7**d**. The thickness is usually slightly greater in boiler than in girder work.

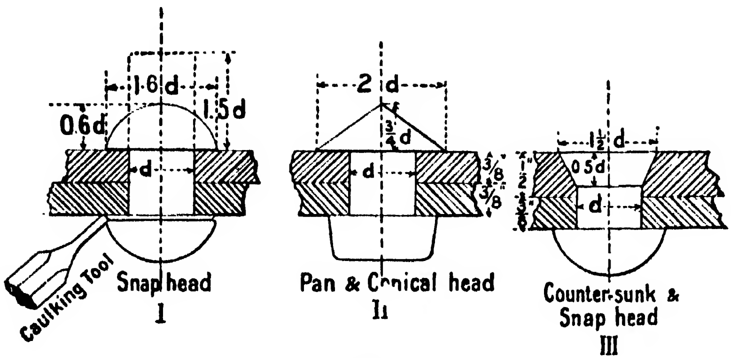


FIG. 50.

Conical head. A form of rivet head occasionally used in hand riveting is the conical head shown at (**II**) (Fig. 50). The spread, or diameter, of the head is twice the diameter of the rivet and the height of the head $\frac{3}{4}$ times the diameter.

Countersunk head. This form of head weakens the plate through which it passes and is not so trustworthy as either of the forms **I** and **II**; it is only used when the surface of the plate must be free from projections. The proportions adopted are indicated at **III**, Fig. 50.

Drawing a rivet head. From the proportions of the rivet head (Fig. 50) it would be possible in any given case to calculate its dimensions. It is, however, much better to obtain these proportions by a graphic method as follows: At one extremity of the diameter **AB**, draw a line **AF** at 60° to **AB** (Fig. 51). With **B** as centre, draw an arc of a circle touching the line **AF** at **E** and intersecting the centre line at **D**.

Mark off **CD** = **BE**, then the head is drawn by using the centre **C** and radius **BE**.

Diameter of rivet. A rough rule sometimes employed is to make the diameter of the rivets equal to twice the thickness of the plates when the plates are less than $\frac{1}{2}$ inch in thickness, and equal to one and a

half times the thickness of the plate when the thickness of the plate is $\frac{1}{2}$ inch and upwards. The usual empirical rule is given by the equation

$$d = 1 \cdot 2\sqrt{t},$$

where d is the diameter of the rivet, and t the thickness of the plate.

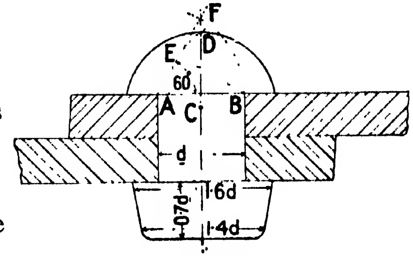
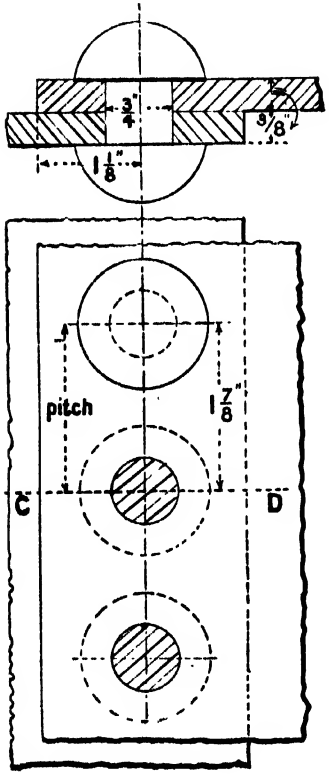


FIG. 51.



Example. Find the diameter of the rivets suitable for plates $\frac{9}{16}''$ thick.

$$d = 1 \cdot 2\sqrt{\tfrac{9}{16}} = 0 \cdot 9''.$$

The rough rule mentioned above would give

$$\tfrac{3}{2} \times \tfrac{9}{16} = 0 \cdot 8439''.$$

As values of t are usually fractional, frequently a little manipulation will simplify the calculation. Thus, if t is $\frac{3}{8}''$, the numerical value of d can be found by extracting the square roots of 3 and 8 and dividing one by the other. Instead of performing this somewhat long and laborious operation, we may multiply numerator and denominator by 8, when the numerator becomes 24, and it is only necessary to divide the square root of 24 by 8. The work is carried out readily in this and all other cases by four-figure logarithms or by the slide rule.

Single riveted lap joint. This form of joint is shown in Fig. 49. As any length of the joint will be simply the aggregate of all the small strips into which the joint may be assumed to be divided, it is only necessary, as in Fig. 52, to draw a strip equal in length to twice the pitch.

In working drawings, the rivet heads are shown usually in the sectional elevation (Fig. 52); but, in the case of the plan, instead of drawing circles representing the heads of the rivets, it is usual to draw circles equal in diameter to the rivets and to section as shown.

In girder work, and in other cases where a comparatively large number of rivets occur, one or two rivets only are shown, the centres of the remainder being indicated simply by small crosses.

Caulking and fullering. The edges of the plates forming the joints of a boiler, etc., are subjected to the processes of *caulking* and *fullering* to ensure that the two plates are in contact along the whole length of the joint. Caulking is indicated at (I) (Fig. 50), and consists in burring down a narrow strip of metal close to the edge of the plate. Fullering is the better method, and is carried out by using a blunt-nosed tool, the thickness of which is equal to that of the plates. It resembles in many respects the caulking tool already described.

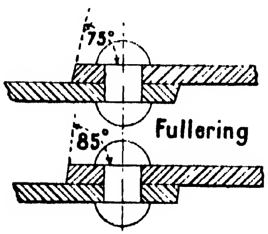


FIG. 53.

The edges of the plates are planed usually to an angle of about 75° to facilitate the process of fullering, and the edges are forced up by the fullering tool until the angle is about 85°, as in Fig. 53. In this manner the two plates are brought into close contact in any slack places which might otherwise occur, thus ensuring a tight joint.

In the design of a riveted joint, when the thickness of the plates is known, the diameter of the rivet may be obtained from $d = 1{\cdot}2\sqrt{t}$; then, from given or assumed values of f_s or f_t, the numerical value of the pitch can be calculated. A rough rule for a single riveted lap-joint is to add $1\frac{1}{8}''$ to the diameter of the rivet, a fact which is expressed by the relation $p = d + 1\frac{1}{8}''$.

Example. Draw the projections of a single riveted lap joint; thickness of plates, $\frac{3}{8}''$; diameter of rivets, $\frac{3}{4}''$. Scale full size.

Commence by drawing a horizontal line and two lines parallel to and $\frac{3}{8}''$ from it. Draw a vertical centre line and mark off on each side of it the radius of the rivet. Complete the projection of the rivet by drawing the heads of the rivet. Mark off, on each side of the rivet, a distance of $\frac{3}{4}''$ to represent the margin, and complete the sectional elevation by drawing the section lines. The plan projected from the elevation can now be drawn. The elevation represents a section on a line CD (Fig. 52). The pitch is given by $p = \frac{3}{4}'' + 1\frac{1}{8}'' = 1\frac{7}{8}''$.

Double riveted lap joint. A double riveted lap joint will be best understood by repeating, as follows, the steps necessary to draw full size a sectional elevation and plan of a double riveted lap joint. Use $\frac{3}{8}''$ plates and $\frac{3}{4}''$ rivets.

Commence by drawing a horizontal line and two lines at $\frac{3}{8}''$ from it. Draw the first rivet A′ (Fig. 54),

making the distance from the centre of the rivet to the edge of the plate $1\frac{1}{2}$d, where d denotes the diameter of the rivet.

To obtain the plan, commence by drawing a circle C of $\frac{3}{4}''$ diameter. Measure off a distance equal to the pitch, $p = d + 2\frac{1}{4}''$, and draw the circle representing the second rivet. To obtain the centre line of the second row of rivets, the diagonal pitch p_1 is made equal to $\frac{2p+d}{3}$; or roughly, draw a vertical line parallel to the former and at a distance 2d from it. When the circles denoting the second row of rivets have been inserted, the elevation can be obtained by projection. As any section plane, such as that indicated by the line AB (Fig. 54), does not pass through these rivets, they are indicated in elevation by dotted lines.

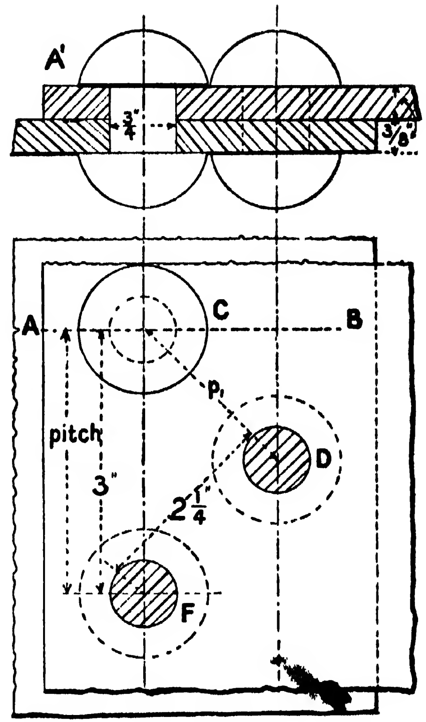


Fig. 54.—Double Riveted Lap Joint.

The pitch p is obtained by substituting the values in

$$p = d + 2\tfrac{1}{4} = \tfrac{3}{4}'' + 2\tfrac{1}{4}'' = 3''.$$

The diagonal pitch is obtained from

$$p_1 = \frac{2p+d}{3} = \frac{6\frac{3}{4}}{3} = 2\tfrac{1}{4}''.$$

Hence, with a radius $2\frac{1}{4}''$ and with centres C and F (Fig. 54), describe arcs of circles intersecting at a point D. D is the centre required, and a circle with centre D and radius $\frac{3}{8}''$ denotes the plan of the rivet.

The elevation of the rivet is determined by projection. The elevation and plan of the riveted joint are completed as shown.

The horizontal width w between the two centres is 1·68″, though the rough rule w = 2d would give 1·5″.

Butt joint. In a butt joint the connection between the two plates may be made either by a single plate (or *butt strap* as it is frequently termed), or by means of two butt straps, one above and the other

below the two plates to be joined. The former arrangement is shown at **A** (Fig. 55) and the latter at **B**. The latter is the better arrangement of the two.

When a single cover plate is used, the thickness of the plate is made about $1\frac{1}{8}$ times the thickness of one of the plates. When two plates are employed the thickness of each may be $\frac{5}{8}$ the plate thickness.

> *Example.* In a butt riveted joint (Fig. 55) the plates are $\frac{3}{8}''$ thick and the rivets $\frac{3}{4}''$ diameter. Draw a sectional elevation and plan of the joint, (*a*) using a single cover plate, (*b*) using a double cover plate. Scale full size.

Combined lap and butt joint. A joint sometimes used in locomotive boilers is shown in Fig. 56. It is known as a combined lap and butt joint. In this case there are three rows of rivets, the pitch of the rivets in the outer rows being twice that in the middle row. The peculiar form of the cover plate makes the joint a somewhat expensive one to produce.

> *Example.* Draw two views of a combined lap and butt riveted joint (Fig. 56); plates $\frac{3}{8}''$ thick, rivets $1\frac{3}{8}''$ diameter, pitch of the outer rows of rivets 4″, and of the inner rows 2″. Scale full size.

Resistance of a riveted joint to fracture. In considering the strength of a single riveted lap joint, such as the joint in a boiler shell subjected to tensile force, it is only necessary to consider a strip of plate of width equal to the pitch. The consideration of the whole length of the joint would simply mean that of the aggregate of all such strips. Such a strip might fracture in any of the four ways indicated at (i), (ii), (iii), and (iv) (Fig. 57).

Let p denote the pitch, t the thickness of the plates, and d the diameter of the rivets.

(i) The joint might fracture by the tearing across of the plates at the weakest part, as at **e, m,** (Fig. 57).

Area of section at $em = (p-d)t$.

If f_t denotes the tensile strength of the plates,

$$\therefore \text{ resistance of strip} = (p-d)tf_t \qquad (1)$$

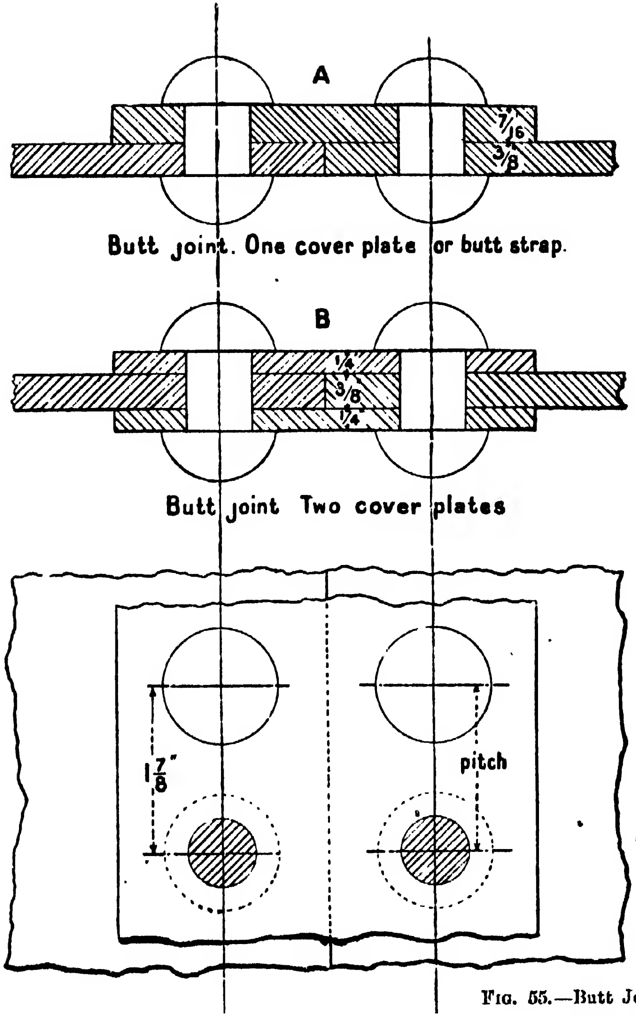


FIG. 55.—Butt Joint.

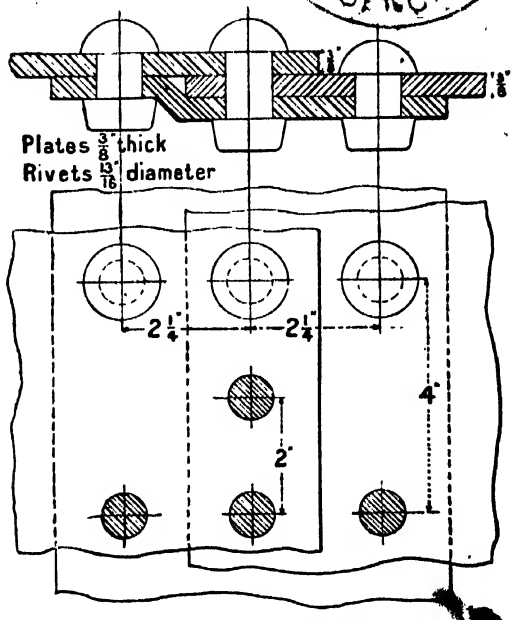


FIG. 56.—Combined Lap and Butt Joint.

(ii) The joint might fracture by the shearing of the rivets as at (ii) (Fig. 57).

The resistance to shearing of a rivet of diameter d is the area of the rivet multiplied by the shearing strength of the material.

$$\therefore \frac{\pi}{4}d^2 \times f_s, \quad \dots\dots\dots (2)$$

where f_s denotes the shearing strength of the material.

The joint will have a maximum resistance when the resistance to tearing is equal to the resistance to shearing. Hence, equating the tearing and shearing resistances, we have

$$(p-d)tf_t = \frac{\pi}{4}d^2 f_s. \quad \dots\dots\dots (3)$$

From (3), when t is known and therefore d, the value of p can be obtained from known values of f_s and f_t. In many actual cases f_s is very nearly equal to f_t. Assuming the two to be equal, from (3) we have

$$(p-d)t = \frac{\pi}{4}d^2.$$

Modes of fracture of a single riveted lap joint.

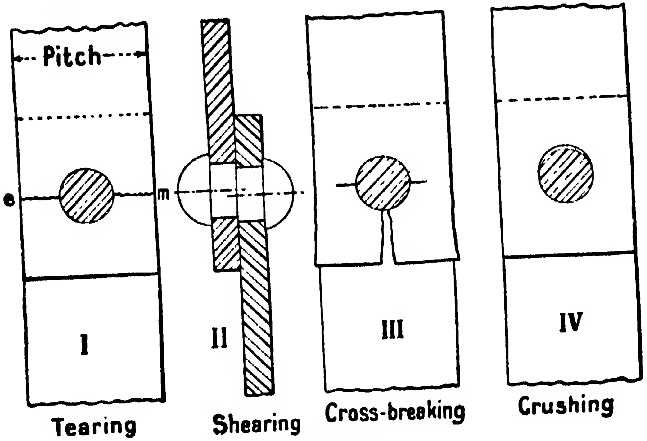


FIG. 57.

Example. In a single riveted lap joint the plates are $\frac{3}{8}''$ thick. Find the diameter and the pitch of the rivets. Assuming $f_s = f_t$,

$$d = 1{\cdot}2\sqrt{t} = 1{\cdot}2\sqrt{\tfrac{3}{8}}.$$

$$\log d = \log 1{\cdot}2 + \tfrac{1}{2}(\log 3 - \log 8) = \log 1{\cdot}8662\,;$$

$$\therefore\ d = 0{\cdot}7348''.$$

The rough rule $d = 2t$ would give $d - 0{\cdot}75''$.

$$(p-d)f_t t = \frac{\pi}{4}d^2 f_s\,;$$

$$\therefore\ p = \frac{\pi d^2}{4t} + d = 0{\cdot}36\pi + 1{\cdot}2\sqrt{t}$$

$$= 1{\cdot}8658''$$

The rough rule $p = d + 1\frac{1}{8}''$ would give

$$p = \tfrac{3}{4} + 1\tfrac{1}{8} = 1{\cdot}87.$$

Two other modes of fracture are shown at (iii) and (iv) (Fig. 57). The third form of fracture is due to the breaking of the plate in front of the rivet, and may be provided for by allowing an increase in the margin of the plate.

The fracture shown at (iv) is due to the crushing of the plate and the rivet. In practice, the two first-named methods of fracture are of the utmost importance in the design of a riveted joint.

Efficiency of joint. The ratio of the strength of the joint to the strength of the solid plate is called the efficiency of the joint.

$$\therefore\ E = \frac{(p-d)tf_t}{ptf_t}, \text{ or } \frac{\pi}{4}\frac{d^2f_s}{ptf_t},$$

where E denotes the efficiency.

Example. Given $p = 1\frac{7}{8}''$, $t = \frac{3}{8}''$, $d = \frac{3}{4}''$, find E.

$$E = \frac{p-d}{p} = \frac{1\frac{7}{8} - \frac{3}{4}}{1\frac{7}{8}} = 0{\cdot}6 \text{ or } 60\%.$$

In the case of a double riveted lap joint the shearing resistance is doubled, and we obtain

$$(p-d)tf_t = 2 \times \frac{\pi}{4}d^2f_s.$$

Example. In a double riveted lap joint the plates are $\frac{3}{8}''$ thick. Find the diameter and pitch of the rivets. Assume $f_s = f_t$.

$$d = 1{\cdot}2\sqrt{\tfrac{3}{8}} = 0{\cdot}7348'',$$

$$(p-d)tf_t = \frac{\pi}{2}d^2f_s;$$

$$\therefore\ p - d = \frac{\pi d^2}{2t},$$

or

$$p = \frac{\pi \times d^2}{2t} + d$$

$$= 0{\cdot}72\pi + 1{\cdot}2\sqrt{\tfrac{3}{8}} = 2{\cdot}996''.$$

The rough rule $p = d + 2\frac{1}{4}''$ gives $p = 3''$.

Design for a joint. A common practical method of designing a joint for a boiler is as follows:

Let P denote the pressure of the steam in lbs. per sq. in.; D the diameter of the boiler, and t the thickness of the shell plates in inches. Assuming a working stress of about 5 tons per sq. in. (denoted by f_t), the thickness of the plate t may be calculated from $t=\frac{PD}{2fE}$, where E denotes the efficiency of the joint, E is usually taken to be from 60 to 80 per cent.

Having obtained the thickness of the plate, the diameter of the rivet is obtained from $d=1{\cdot}2\sqrt{t}$, where d denotes the diameter of the rivet. The pitch p is obtained from $E=\frac{p-d}{p}$. The number of rows of rivets is obtained from $f_t(p-d)t_t=n\times\frac{\pi}{4}d^2f_s$, usually $\frac{f_s}{f_t}=\frac{23}{27}$.

It is not necessary to consider the crushing of the rivet, provided that the pitch is not less than three times the diameter of the rivet for single row rivets, nor less than five times the diameter of the rivet for double rows, or seven times the diameter of the rivet for triple rows, since f_c may be taken safely to be $2f_t$.

Riveting in bridge and girder work. In bridge and girder work, instead of employing the usual empirical rule $d=1{\cdot}2\sqrt{t}$, the diameter of the rivet is fixed by considerations of the shearing strength required. The thickness of plate is made so that the bearing stress on the metal at the hole does not exceed from 8 to 10 tons per sq. in.

For bridge work, the diameter of the rivet is seldom made less than $\frac{7}{8}''$ for the main structure, such as main angles, flanges, attachment of diagonal bracings to booms, etc.

In the case of work which does not carry the rolling load, such as floor plates, etc., the diameter may be $\frac{3}{4}''$ or $\frac{5}{8}''$.

The diameter d is not changed by amounts less than $\frac{1}{8}''$. Common values of d are $\frac{3}{4}''$, $\frac{7}{8}''$, $1''$, and occasionally $1\frac{1}{8}''$ and $1\frac{1}{4}''$. The rivet holes are drilled usually about $\frac{1}{16}''$ larger than the rivet to allow for the free entry of the hot rivet, and also for any slight deviation of the alignment of the holes. Thus, assuming the riveting to be carefully carried out, a rivet $\frac{3}{4}''$ diameter would be $\frac{13}{16}''$ when finished.

Flat bars, angle irons, etc. In the case of flat bars, etc., the relation of the diameter of the rivet to the width of the bar is given by $w=4d$, where w denotes the width of the plate and d the diameter of the rivet.

In angle irons, the distance S_1 (Fig. 58) is not less than $1\frac{1}{4}''$ for $\frac{7}{8}''$ rivets, and the distance S_2 is not less than d.

As already indicated, the size of the rivet is calculated from considerations of the bearing and shearing

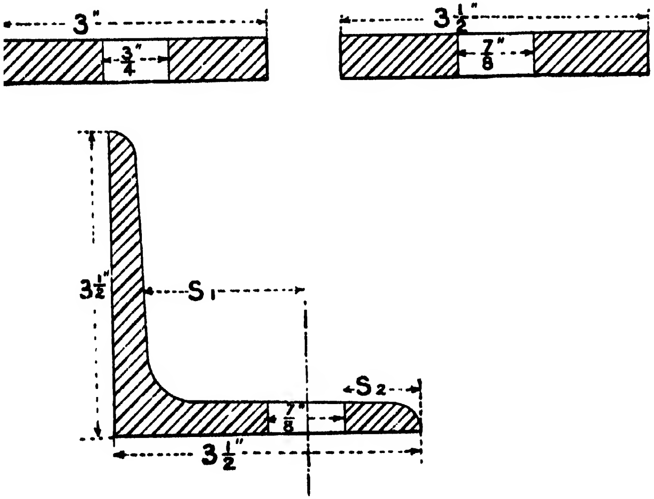


FIG. 58.

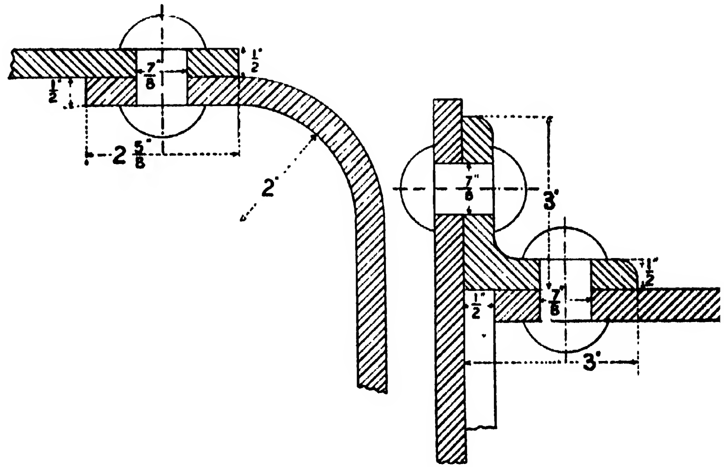


FIG. 59.—Plates at right angles.

areas. In shear, the net area of the rivet in the plane of shear is made equal to $1\frac{1}{2}$ times the plate area. Thus, for a single riveted lap joint, we obtain

$$(p-d)t = \frac{2}{3}\frac{\pi}{4}d^2.$$

lates at right angles. The joint between two plates at right angles to each other may be made by g one of the plates, or by using an angle iron. The two methods (Fig. 59) are commonly used at ont and the back end respectively of a boiler. The joint obtained by bending is called a *flanged joint*,

and that when an angle iron is used, an *angle iron joint.* In the former, the radius of the curve to which the plate is bent should not be less than 4 times the thickness of the plates.

Flue joints. Plain furnace flues, such as those generally used in Lancashire and Cornish boilers, are liable to comparatively great alterations in length, due to changes of temperature, and, since the ends

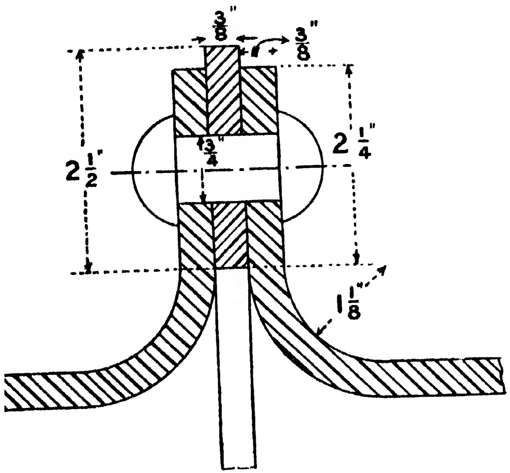


Fig. 60.—Flanged Seam.

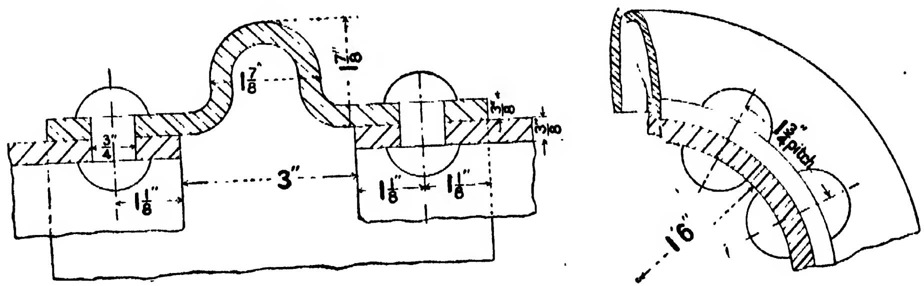
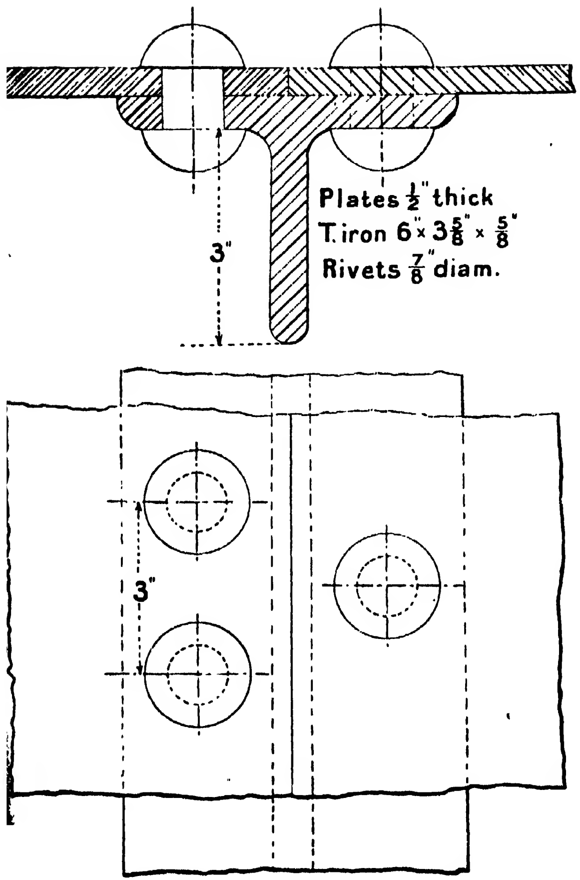


Fig. 61.—Bowling Hoop.

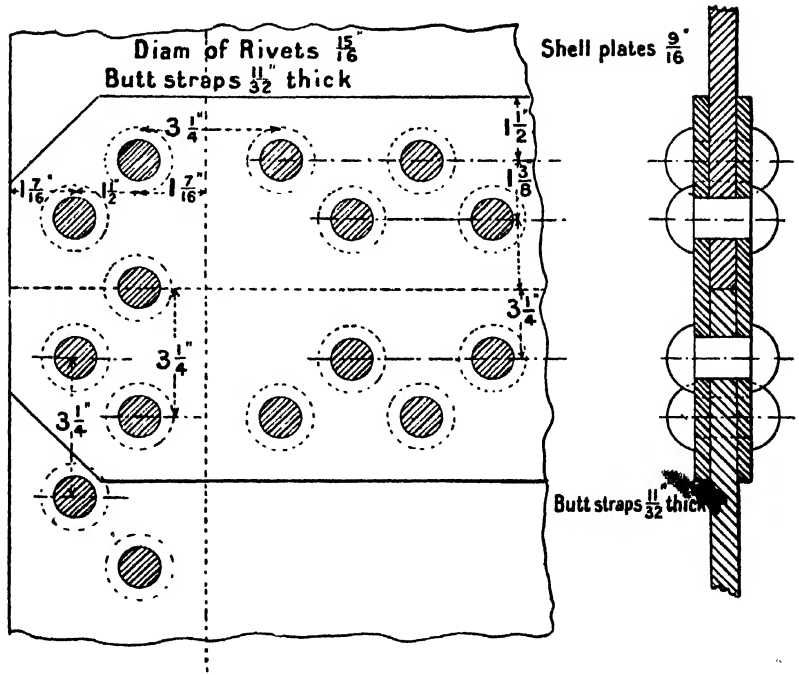
of the flues are fixed in the ends of the boiler it is necessary to provide a form of joint which will admit an alteration of length to take place. Of the forms of joints which may be used for such a purpose (Figs. 60, 61), the *Adamson Ring*, or *Flanged Seam*, is usually considered to be the best joint. Reference to Fig. 60 will show that the ends of the flue sheets are flanged and riveted to a ring inserted between them. The flanging is effected to a radius 2 to 3 times the thickness of the plates. This construction prevents grooving, permits longitudinal expansion, and also facilitates the process of making and maintaining a tight joint. It will be noticed that in this arrangement the heads of the rivets are not subjected to the action of the flame.

Example. Draw the flanged seam (Fig. 60). Scale full size.



Plates $\frac{1}{2}$" thick
T. iron 6" × 3$\frac{5}{8}$" × $\frac{5}{8}$"
Rivets $\frac{7}{8}$" diam.
3"
3"

FIG. 62.



Diam of Rivets $\frac{15}{16}$"
Butt straps $\frac{11}{32}$" thick
Shell plates $\frac{9}{16}$"
Butt straps $\frac{11}{32}$" thick
3 $\frac{1}{4}$"
1 $\frac{7}{16}$"
1 $\frac{1}{2}$"
1 $\frac{7}{16}$"
1 $\frac{1}{2}$"
1 $\frac{3}{8}$"
3 $\frac{1}{4}$"
3 $\frac{1}{4}$"
3 $\frac{1}{4}$"

FIG. 63.

Example. Riveted joint. Angle irons $3'' \times 3'' \times \frac{5}{8}''$. Rivets $\frac{7}{8}''$ diameter. $2''$ pitch. Plates $\frac{1}{2}''$ thick. Draw to scale $\frac{1}{2}$ size (Fig. 61).

Example. Tee-iron joint. T-iron $6'' \times 3\frac{5}{8}'' \times \frac{5}{8}''$. Plates $\frac{1}{2}''$ thick. Rivets $\frac{7}{8}''$ diameter and $3''$ pitch. Draw half size (Fig. 62).

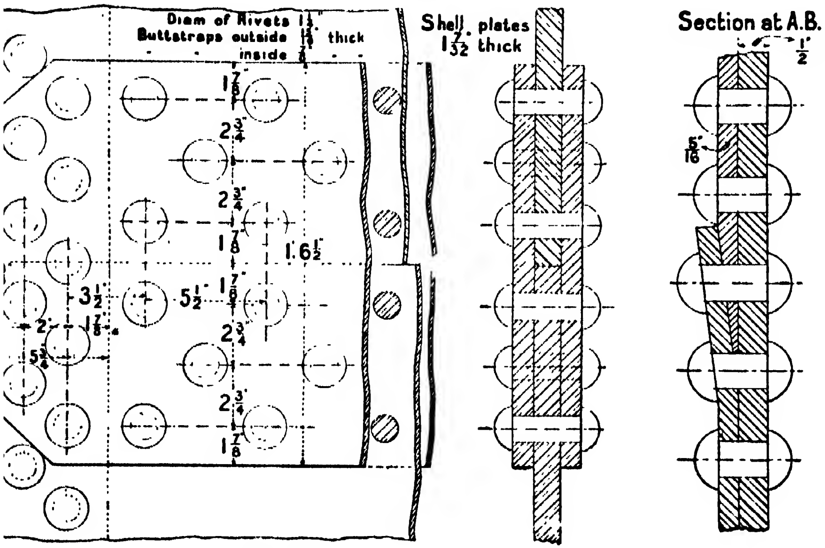


FIG. 64.

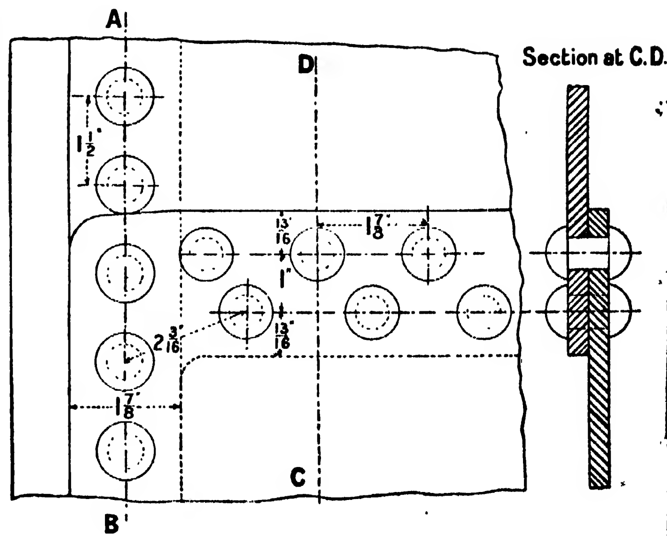


FIG. 65.

Examples of boiler joints. (i) Draw the two views of a double riveted butt joint at the junction of a ring and longitudinal joint (Fig. 63). Shell plates $\frac{9}{16}''$. Butt straps $\frac{11}{32}''$. Rivets $\frac{15}{16}''$. Scale full size. Find the efficiency of the joint and also the safe working pressure, the diameter of the boiler being $8'\ 4''$. $f_t = 5$ tons per sq. in.;

[Ans. 71 per cent., 89 lb. per sq. in.]

(ii) Draw the two views shown (Fig. 64). Shell plates $1\frac{7}{32}''$. Butt straps, outside $\frac{15}{16}''$, inside $\frac{7}{8}''$. Rivets $1\frac{1}{4}''$ diameter. Scale full size. Find the efficiency of the joint. If the diameter of the boiler is 16′ 4″, what will be the safe working pressure? $f_t = 7{\cdot}2$ tons per sq. in.

[Ans. 77·3 per cent. 155 lb. per sq. in.]

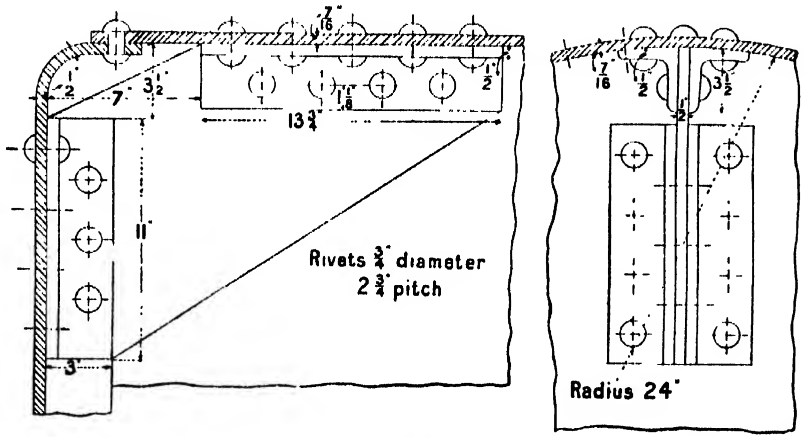


Fig. 66.—Gusset Stay.

(iii) Two views of a boiler joint at the junction of a ring and a longitudinal joint (Fig. 65). Draw full size. Shell plates $\frac{5}{16}''$ and $\frac{1}{2}''$. Rivets $\frac{5}{8}''$. Find the efficiency of the joint. If the diameter of the boiler is 3′ 4″, and the working pressure 140 lbs. per sq. in., what is the magnitude of the working stress adopted?

[Ans. 66·7 per cent., 6 tons per sq. in.]

Gusset stays. The flat ends of a boiler are strengthened or stayed by means of *bar stays* (Fig. 85), and by *gusset stays* (Fig. 66). These stays connect the shell plates to the flat end.

Example. Draw and complete the two views of the gusset stay (Fig. 66). Scale half size. [B.E.]

EXERCISES. II.

1. Sketch a $\frac{3}{4}''$ rivet, showing the form and proportions of the rivet head.

2. Show by sketches the method of joining the plates of a cylindrical boiler at a place where a longitudinal joint meets a ring joint. Explain why the longitudinal joints are usually of a different construction from that of the transverse or ring joints.

3. Show by sketches a single riveted, and a double riveted lap joint, also a butt joint suitable for plates $\frac{3}{8}''$ thick. What in each case is (i) the least width of overlap, and (ii) the least distance of the rivet holes from each other and from the edge of the plate?

4. Draw a section and plan of a double riveted butt joint with $\frac{3}{4}''$ plates, $1\frac{1}{8}''$ rivets, double cover straps $\frac{5}{8}''$ thick, pitch $4''$. Scale half size.

5. Give dimensioned sketches of a double riveted lap joint suitable for $\frac{1}{2}''$ boiler plates. Mark on the sketch the width of overlap and margin, assuming $f_s = f_t$.

6. Sketch with dimensions a double riveted butt joint with two butt straps suitable for the longitudinal joint in a steel boiler with $\frac{5}{8}''$ plates. Explain how one of the rivets is put in place and riveted.

7. Draw two views of a double riveted lap joint, first, when the rivets are arranged in zig-zag form (Fig. 55); and secondly, when they are placed in chain, *i.e.* when all the centre lines are parallel to each other. Point out the advantage due to the former arrangement.

8. Show by a sketch a flanged seam used for a furnace flue in a Lancashire or Cornish boiler.

9. Sketch in section common forms of wrought iron and mild steel used in construction. Show how in a built-up girder the web plate is connected to the flanges. What size rivets would be used for $\frac{1}{2}''$ plates?

10. Show three methods of connecting together parallel plates such as are used in locomotive fire boxes.

11. Give a section through a **T**-iron joint showing the construction.

12. Show by sketches how two plates at right angles to each other may be connected by means of angle irons and rivets.

13. Show by sketches the methods of strengthening a boiler by means of (*a*) a longitudinal bar stay joining opposite flat ends, (*b*) a gusset stay. [**B.E.**]

14. In a single riveted lap joint the plates are $\frac{1}{2}''$ thick, rivets $\frac{7}{8}''$ diameter, pitch $2\frac{1}{4}''$. Assuming the tensile resistance of the plates to be equal to the shearing resistance of the rivets, find whether the joint will fracture by tearing or by shearing.

15. Show the different ways in which a riveted joint may fracture. In a single riveted joint the plates are $\frac{1}{2}''$ thick and the rivets $\frac{7}{8}''$ diameter, calculate the pitch for the greatest strength of joint. The shearing resistance of the rivet is $\frac{3}{4}$ the tensile resistance of the plate per square inch of section. [B.E.]

16. In a single riveted lap joint the plates are $\frac{5}{8}''$ thick, rivets $1''$ diameter, and pitch $2\frac{1}{4}''$. Find whether the joint will yield by shearing or by tearing, the plates being 10 per cent. stronger in tension than the rivets in shear, per square inch of section. [B.E.]

17. Sketch a single riveted lap joint for $\frac{1}{2}''$ plates, using $\frac{7}{8}''$ rivets. Show how such a joint may fracture.

Calculate the pitch, (i) assuming the tearing resistance of the plates and the shearing resistance of the rivets to be equal.

(ii) When the safe shearing strength is 7800 lbs. per sq. in., and the safe tensile strength is 10,000 lbs. per sq. in.

18. A treble-riveted lap joint has twice as many rivets in the middle row as in the outer rows. Plates $\frac{3}{4}''$ thick. Rivets $1''$ diameter. Pitch of outer rows $4\frac{1}{2}''$.

Draw cross section and plan. Scale $\frac{1}{2}$.

19. In a single riveted lap joint the plates are $\frac{5}{8}''$ thick, rivets $1''$ diameter and pitch $2\frac{1}{4}''$. Find the efficiency of the joint.

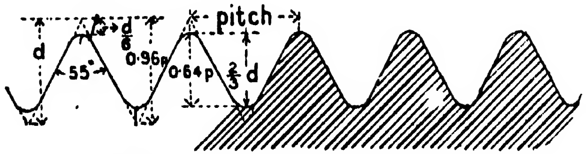
20. In a double riveted lap joint for $\frac{1}{2}''$ plates, the rivets are $\frac{7}{8}''$ diameter, the longitudinal pitch is $2\frac{3}{4}''$, the diagonal pitch is $2\frac{1}{8}''$, and the overlap is $4\frac{1}{4}''$. Sketch this joint to scale, full size, on squared paper, showing two views, one being in section. [B.E.]

21. In a single riveted lap joint the plates are $\frac{3}{8}''$ thick, rivets $\frac{3}{4}''$ diameter. Assuming the tearing resistance of the plates to be 30 tons per sq. in. and the ultimate shearing strength of the rivets 24 tons per sq. in., find the pitch. Make a dimensioned sketch of the joint.

CHAPTER III.

SCREWS, BOLTS AND NUTS.

Screw threads. The usual form of screw thread in use by engineers is known as the *Whitworth thread.* Other forms, such as *gas threads* used for piping, are employed for special purposes.



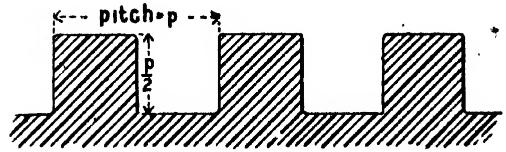
Section of Whitworth V-thread.

FIG. 67.

Vee thread. What is called the *Vee thread* is shown in Fig. 67. It will be seen that the sides of the thread are inclined at an angle of 55°; they do not terminate in a sharp edge, but are rounded off at the top and bottom to a distance equal to $\frac{1}{6}$ of the depth of the thread.

Pitch. The pitch of a single threaded screw is the distance between two consecutive ridges, or the amount by which the distance between the head of the bolt and its nut would increase or diminish for one rotation of the screw.

For any diameter of bolt in ordinary use the pitch may be obtained from tables, such as Table V., p. 243. Thus, on a bolt of 1 inch diameter there are 8 threads in an inch of its length, and hence the pitch is $\frac{1}{8}''$. It is convenient to express all the proportions of a screw thread in terms of the pitch.



Section of square thread

FIG. 68.

Square thread. Another common form of screw thread is the *square thread*, a section of which is shown in Fig. 68. The pitch of a square thread is usually twice that of the corresponding triangular thread. Thus, as already indicated,

an inch bolt with a Whitworth triangular thread would have 8 threads per inch length, but a square threaded bolt of the same diameter would have 4 threads per inch.

Comparing the two forms of thread, it will be seen that more material is cut away in forming a square thread than in making a triangular thread of the same diameter. The triangular is therefore stronger than the square thread. The triangular thread is used for holding down bolts and for other purposes where strength is required. In this form of thread the direction of the force between the bolt and nut is inclined to the axis of the screw, this not only increases the friction between the bolt and nut, but also gives a tendency to burst the nut.

In the square thread, the direction of the mutual force between the bolt and nut is nearly parallel to the axis of the bolt. Hence this form is used for a variety of purposes, such as in book presses, etc., in which the transmission of motion is concerned.

The edges of a square threaded screw are slightly rounded off, an expedient which not only makes it safer and easier to handle, but also renders it less liable to damage.

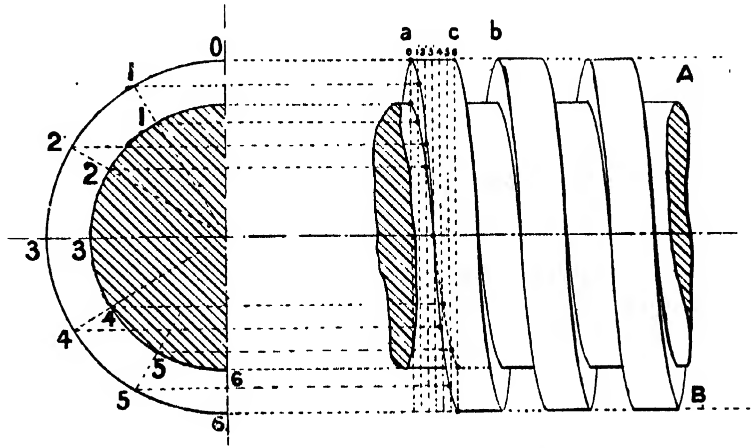


FIG. 69.—Projection of a Square Thread.

Screw thread or helix. In many cases, such as in screws of comparatively large size, in spiral springs, etc., it is necessary to be able to draw with some approach to accuracy the form of a screw thread. The method may be shown by an example as follows.

Example. Draw a square threaded screw, using the following dimensions; outside diameter, 4″; inside diameter, 3″; pitch, 1″.

Commence by drawing two semi-circles with radii of 2″ and $1\frac{1}{2}$″ respectively. Project the lines **A** and **B**, *i.e.* 4″ apart (Fig. 69). Divide the semi-circle into any convenient number of equal parts and number these as shown. Mark off a distance **ac** denoting half the pitch, and divide this distance into the same number of equal parts as the semi-circle. Draw the vertical lines 0′, 1′, 2′ ... 6′; then

points on the required curve are obtained by projections from the points 0, 1, 2 ... 6 to meet corresponding lines 0′, 1′ 2′ ... 6′. The points obtained in this manner may be marked on a piece of celluloid, thin wood, or cardboard, and an even curve drawn through the points. Any irregularities in such a curve may be detected and rectified by placing the surface on which the curve is drawn on a level with the eye and looking along the curve.

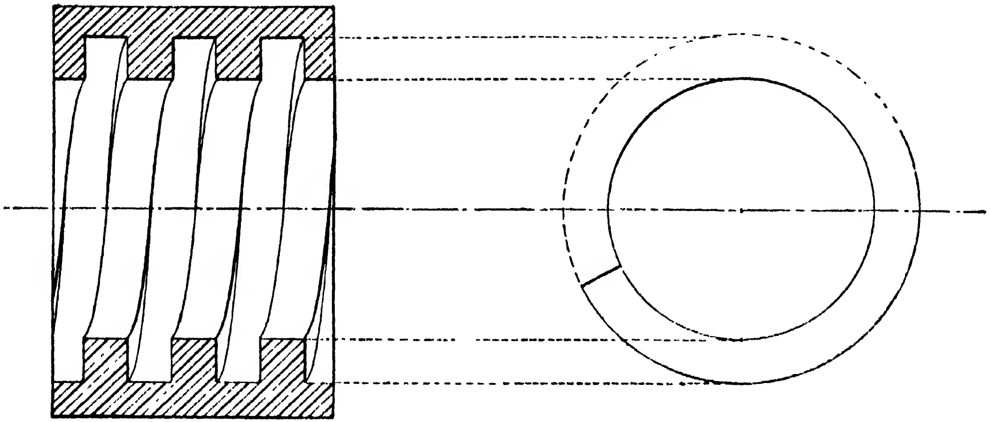


FIG. 70. Section of Nut.

The curve should be cut out carefully and the edge made smooth by using a piece of fine sand paper or a smooth file. When finished it may be used as a template to insert all the remaining portions of the curve.

In a similar manner, the curve showing the inner edge of the screw thread may be drawn.

A section of a nut suitable for the screw just drawn is shown in Fig. 70. The curves indicating the screw thread are obtained in the same manner as before.

Conventional methods of representing screw threads. In the majority of cases in which bolts occur in machine drawings, the bolts are not only of small size, but, in addition, the scale is less than full size, and therefore the attempt to draw the true shape of a screw thread would serve no useful purpose. In such cases the screws are usually drawn in a conventional manner. Some of the methods usually adopted are indicated in Fig. 71. Thus, at (I), a triangular screw is represented by a series of small triangles, using for the purpose the 60° set square.

As one turn of the screw corresponds to a distance equal to the pitch, it is only necessary to draw a

vertical line, and to mark off a distance on one side of it equal to half the pitch. When this is done the two series of triangles on the upper and lower edges respectively can be drawn, and the delineation of the screw thread is completed by joining the angular points of the triangles by straight lines.

In a similar manner, we may obtain the square thread shown at (**II**) (Fig. 71). This thread consists of a series of small squares joined by straight lines. Another method frequently adopted, for all except comparatively large screws, is indicated at (**III**). It will be seen that the screw thread is indicated by straight lines drawn at a suitable inclination—the shorter lines denoting roughly the bottom of the thread may be made slightly thicker than the longer lines.

Two other methods are indicated at (**IV**) and (**V**) (Fig. 71). In (**V**) the thread is denoted by dotted lines and in (**IV**) by two thick lines.

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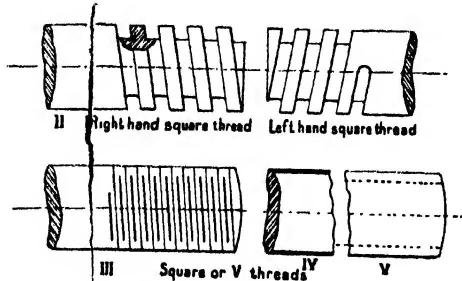
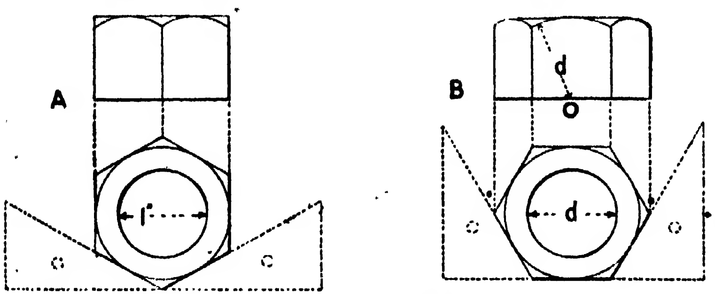


FIG. 71.—Conventional Methods of representing Screw Threads.

Projection of a nut. If a careful examination of a hexagonal nut is made before proceeding to draw it, no difficulty will be experienced in realising that the elevation of a nut may be shown as at **A** (Fig. 72) or as at **B**. The elevation at **A** shows the distance between two flat sides of the nut and at **B** the distance from corner to corner.

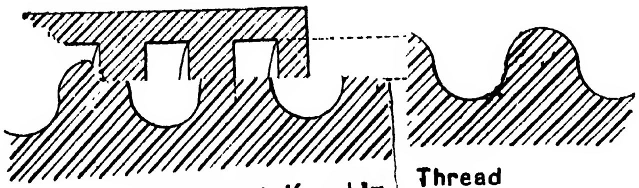
To draw the projections of a nut for a bolt 1 inch diameter, proceed as follows: Commence by drawing a circle 1″ diameter, and with the same centre draw another circle the diameter of which is the width of the nut across its flat sides $= 1\frac{1}{2}d + \frac{1}{8}''$. Using the 30° set square and the T-square, draw the sides of the nut just touching



Projections of a Hexagonal Nut

FIG. 72.

In a similar manner, using the 60° set square, draw the projection of the points on the required cu corresponding lines 0′, 1′ 2′ ges of the nut may be indicated by drawing an arc of a circle with centre **O**, and radius equal to the diameter 1″. The chamfering is completed by drawing two smaller curves, as shown at **B** in Fig. 72.



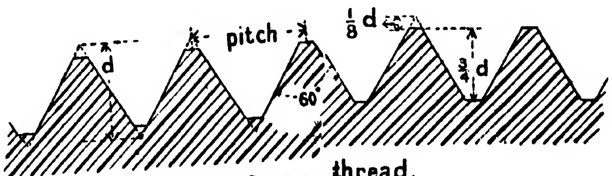
Section of Knuckle Thread

FIG. 73.

Knuckle thread. When a screw thread is liable to be subjected to rough usage, the profile of the thread may be that shown in Fig. 73, which consists of arcs of circles, and is known as a *knuckle thread.*

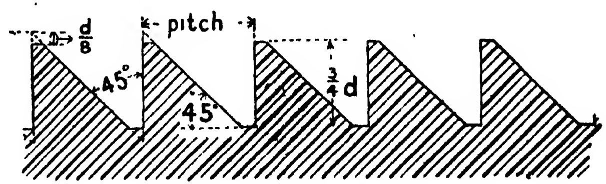
Seller's thread. A section of the *Seller's screw thread* is shown in Fig. 74. It will be noticed that the angle of the thread is 60° and that one-eighth part of the depth is taken off at the top and at the bottom.

Buttress thread. As already indicated, the amount of material removed in forming a square thread renders the screw thread much weaker than the corresponding triangular thread, in which a comparatively



Section of Sellers thread.

FIG. 74.



Section of Buttress Thread

FIG. 75.

small amount is removed. A successful attempt to combine the advantages of the square with the strength of the V-thread has been made in what is called a *buttress thread*, shown in Fig. 75. It will be seen that one side is vertical and the other inclined at an angle of 45°. One eighth of the depth of the thread is cut off at the top and at the bottom.

Proportions of bolts and nuts. The names given to the various parts of a bolt are indicated in Fig. 76.

The sizes of the head and of the nut of a bolt may be obtained from Table V. when the diameter **d** of the bolt is known. Bolts and nuts are, however, of such frequent occurrence in all machines and machine

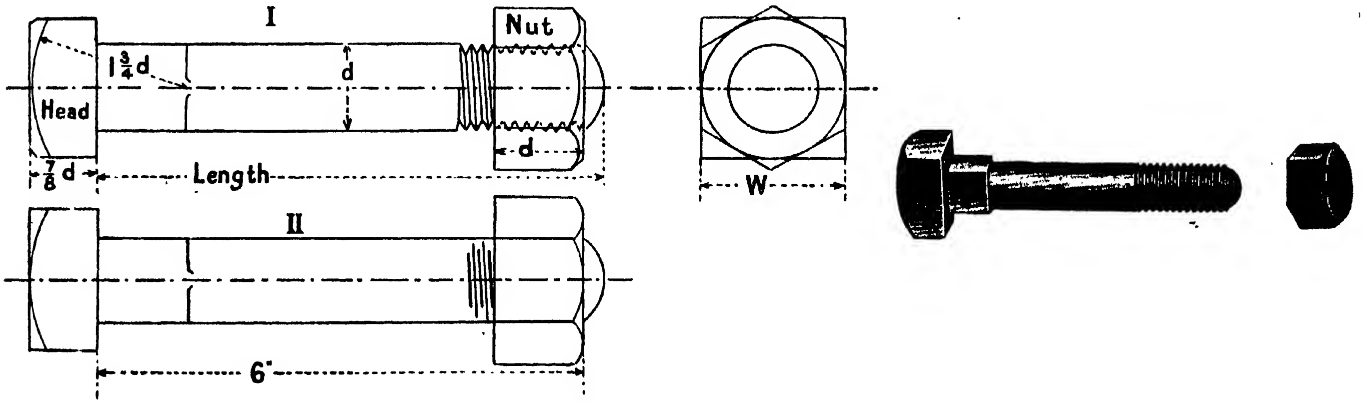


FIG. 76.—Bolt and Nut.

details that it is desirable, when the diameter of a bolt is known, to be able, without reference to tables, to draw it. The following proportions of bolt heads and nuts—which represent fairly average practice—should be committed to memory.

Thickness of bolt head	$=\frac{7}{8}$d.
,, nut ,,	$=$ d.
Width, W, across flat sides	$=1\frac{1}{2}$d $+\frac{1}{8}''$.
Distance from corner to corner	$=1\frac{3}{4}$d $+\frac{1}{8}''$.

When the head of the bolt is made square, as in Fig. 76, the side of the square is $1\frac{1}{2}$d $+\frac{1}{8}''$, and when the head is circular this proportion also gives the diameter of the circle.

The drawings in which bolts and nuts occur are frequently made to a small scale, and to avoid calculation $1\frac{3}{4}$d is used to replace $1\frac{1}{2}$d $+\frac{1}{8}''$. When this replacement is made it is only necessary to mark off on each

side of the centre line a distance $\frac{7}{8}$d, also the distance from corner to corner is made 2d; these proportions are obtained easily from the drawing.

The conventional methods of drawing a bolt and nut are shown at **I** and **II** (Fig. 76).

Example. Draw the elevation, end view, and plan, of a bolt and nut. Bolt 1″ diameter and 4″ long. Write on the drawing the usual dimensions adopted for the various parts.

Fracture of bolts. A bolt may fracture

(1) by tearing;
(2) by the stripping of the thread;
(3) by the bolt head giving way.

Of these, the first is the most important, and in this case the diameter of a bolt may be obtained from the relation

$$(\text{area of bolt}) \times (\text{safe stress}) = \text{load}; \text{ or,}$$

$$\frac{\pi}{4} d_1^2 \times f = P,$$

where d_1 is the diameter of the bolt at the bottom of the thread, and the relation between d_1 and the diameter d is given in Table V., or by $d_1 = 0{\cdot}84d$ approximately. f may be taken to be 3000 lbs. per sq. in. to allow for stresses due to screwing tightly.

Example. A cylinder of 12″ diameter is to be designed. Pressure of steam 100 lbs. Find the size and the number of bolts in the cylinder cover.

$$\text{Area of cylinder} = 12^2 \times 0{\cdot}7854 = 113 \text{ sq. in.},$$

$$P = 113 \times 100 = 11300 \text{ lbs.},$$

$$\therefore \text{ bolt area} = \frac{11300}{3000} = 3{\cdot}767.$$

If $\frac{3}{4}$″ bolts are used, then $n = \dfrac{3{\cdot}767}{0{\cdot}3039} = 12$ bolts.

If $\frac{7}{8}$″ „ „ $n = \dfrac{3{\cdot}767}{0{\cdot}422} = 9$ bolts.

To ensure tight joints, the pitch of the bolts is usually about 5d, where d is the diameter of the bolt. With the spanners in general use, no bolts less than $\frac{3}{4}''$ diameter are used for joints.

Gas threads. Wrought iron pipes of comparatively small size used for the conveyance of gas and water may be fastened together by what are called *nipples* or *couplings* (Fig. 159). To form such a connection, the pipes have a screw thread cut either on the outside or on the inside of the pipe. The depth of the Whitworth thread renders it unsuitable for such a purpose, and the thread used, called a *gas thread*, is finer in pitch and of smaller depth than the Whitworth thread. Thus, the screwed portion of a pipe $\frac{3}{4}''$ internal diameter and 1″ external diameter would have 14 threads per inch of length, or a pitch of $\frac{1}{14}''$ instead of 8 threads per inch of length and a pitch of $\frac{1}{8}''$.

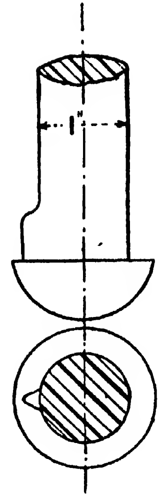


Fig. 77.

Prevention of rotation of bolt. To prevent the rotation of the bolt during the turning of the nut, a small portion of the bolt close to the bolt head is usually left square and fits somewhat loosely into a square hole in one of the pieces to be joined. Another method is to provide a small pin or *snug* immediately under the head of the bolt, and this pin fits a corresponding hole made to receive it. Such an arrangement is shown in Fig. 77.

Forms of bolts and screws. When a bolt and nut cannot be used, other forms which receive special names, such as *tap bolts*, *set screws*, *studs*, etc., are used. A set screw is a screw, or bolt, which presses on a piece so as to prevent the sliding or rotation of that piece, as in Figs. 90, 118, 136, etc.

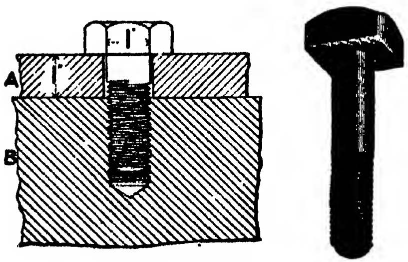


Fig. 78.—Tap Bolt.

Tap bolt. In this form a screw thread is made along a certain length, as in the arrangement in Fig. 78. It will be noticed that the screw passes loosely through one piece A and is screwed into another piece B, in which a hole has been made to receive it.

The heads of **tap bolts**, as in bolts, are of various forms; *i.e.* square, hexagonal, hemispherical, cylindrical, etc.

In some cases, as in Fig. 100, a hole large enough to receive the cylindrical head of the screw is made in one piece, and the screw may be rotated by means of a screw-driver fitting a rectangular hole in the head of the screw.

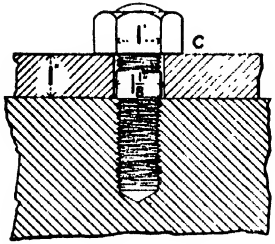


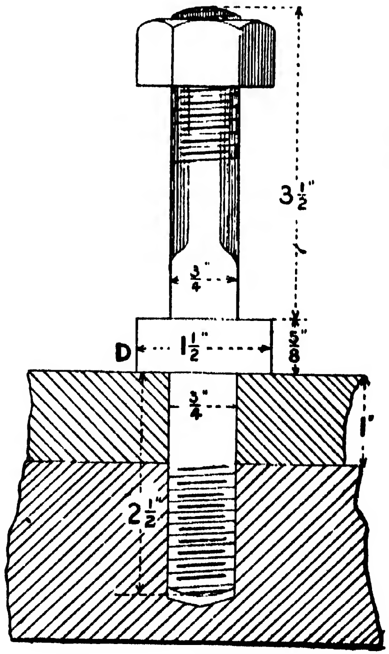
FIG. 79.—Stud.

Studs. A stud, in its simplest form, as at **C** (Fig. 79), consists of a round piece of metal (iron, steel, brass, copper etc.), at each end of which a screw thread is formed. The intermediate portion is used to grip the stud so that it may be screwed firmly into its place. To facilitate this the portion referred to is in many cases made square in cross-section, as at **D** (Fig. 80). Studs and screws are screwed into metal usually for a distance $1\frac{1}{4}$**d** to $1\frac{1}{2}$**d**, where **d** is the diameter of the stud.

Special bolts. Bolts of special shapes are used in machine tools and for other purposes. Three of these are shown at (**a**), (**b**), (**c**) in Fig. 81. The first is called a *hook bolt* from the peculiar hook form given to the head. At (**b**), another form called an *eye-bolt* is shown, and at (**c**) a *tee-headed bolt*. In the last, the projections forming the head of the bolt are only present on two sides of it.

Rag bolt. When a machine is to be secured to stonework, its own weight is not always sufficient to keep it rigidly in position, and some means of fastening it to the stone must be provided. Two forms of bolt frequently used for this purpose are known as *Rag* and *Lewis* bolts. In the former, the lower part of the bolt is made with the tapering sides, and these are usually indented as indicated in Fig. 82. When placed in position, in a corresponding taper hole, the space between the sides of the bolt and the stone in which it is fitted is filled with molten lead. The objections to this form of bolt are the use of the molten lead for fixing and the difficulty of removing the bolt if required to do so.

Lewis bolt. In the Lewis bolt one side of the head of the



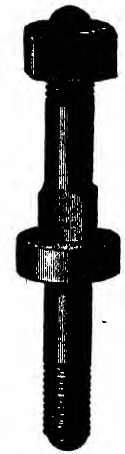


FIG. 80.—Stud.

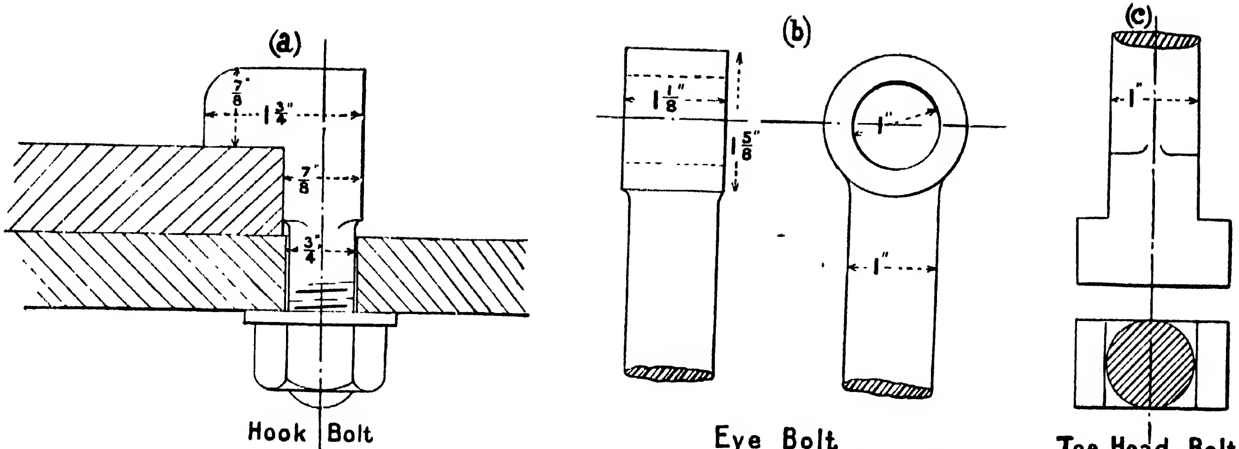


Fig. 81.

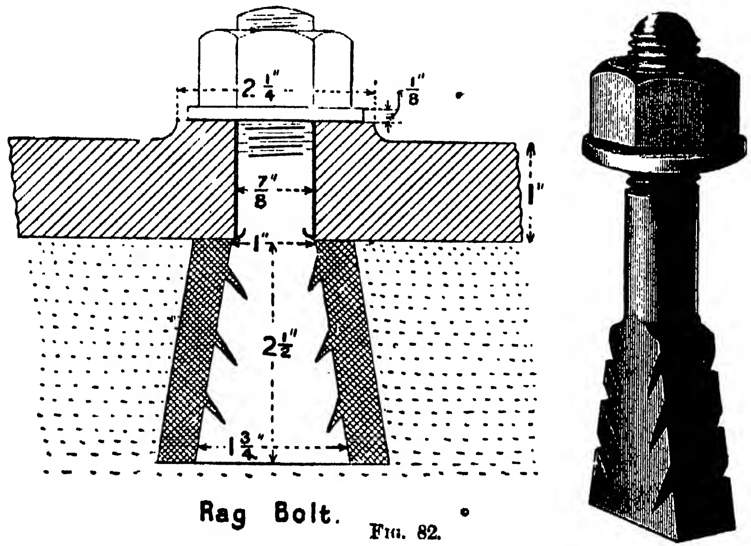


Fig. 82.

bolt is made of a taper form and the other straight, as shown in Fig. 83. The hole in the stone is made to receive the head, which is secured by a cotter as shown.

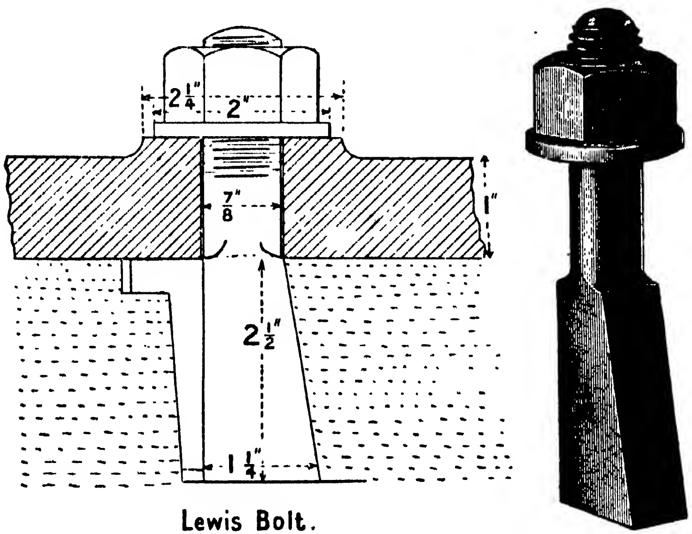


Fig. 83.

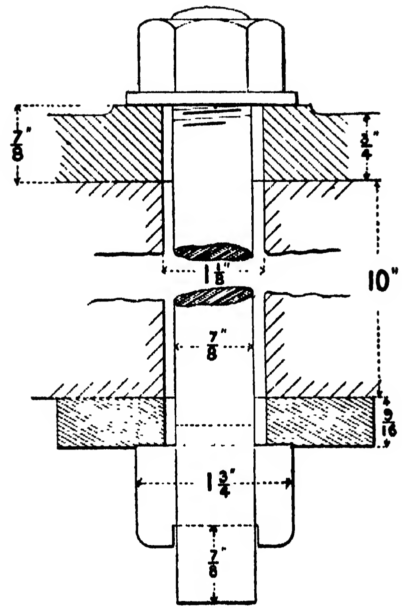


Fig. 84.—Cotter Bolt.

Cotter bolt. In a so-called *cotter bolt*, a rectangular hole is made in the bolt to receive the cotter. One form of such a bolt is shown in Fig. 84, and consists of a comparatively long bolt passing through brickwork or masonry. At some convenient place, a hole is made in the brickwork, or masonry, large enough to allow a cast-iron washer to be threaded on to the bolt. The washer provides a bearing surface

for the cotter. Rotation of the bolt during the process of turning the nut may be prevented by means of a groove on the washer into which the cotter fits. The bolt can rotate only by rotating the washer. As the washer is of comparatively large size and rests against a rough surface, the device effectually prevents the rotation during the process of screwing or unscrewing the nut.

Stay bolt. What are known as *bar stays* or *stay bolts* are used to strengthen the flat ends of a

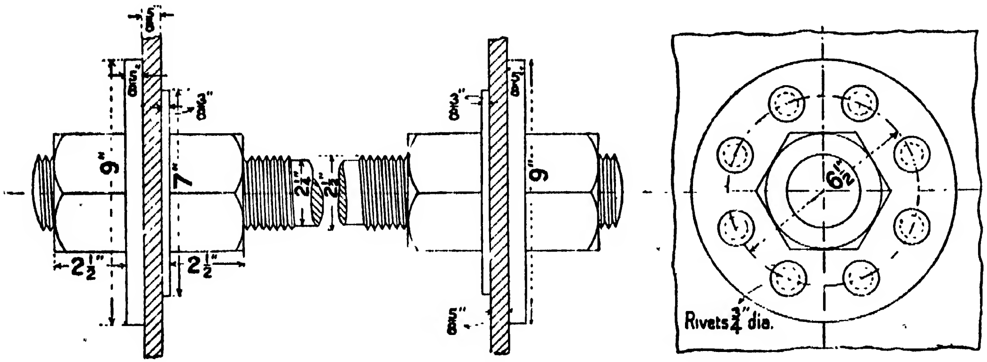


FIG. 85.—Stay Bolt.

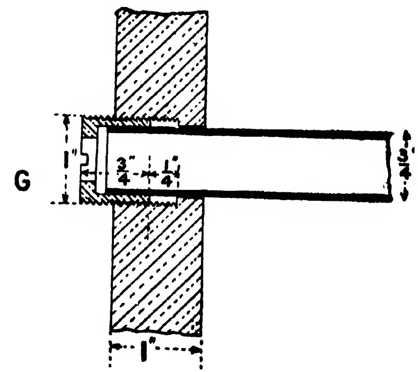


FIG. 86.—Condenser Tube.

cylindrical boiler. These consist of long bolts passing from one flat end to the other. Such bolts frequently have the ends enlarged (Fig. 85), the diameter of the bolt being equal to the diameter at the bottom of the thread. A raised screw thread of this kind is known as a *plus thread.*

Condenser tubes. The tubes are $\frac{5}{8}''$ or $\frac{3}{4}''$ external diameter and about $\frac{1}{20}''$ thick, and to render them watertight in the tube plates, a small screwed ferrule or gland **G** (Fig. 86) is used. This ferrule is made to compress packing placed around the end of the tube.

Screwed stays. The flat sides and back of combustion chambers are stayed by short screws $1\frac{1}{4}''$ to $1\frac{1}{2}''$ diameter. These screws are screwed through the plates, and are either riveted or nuts are used, as in Fig. 87.

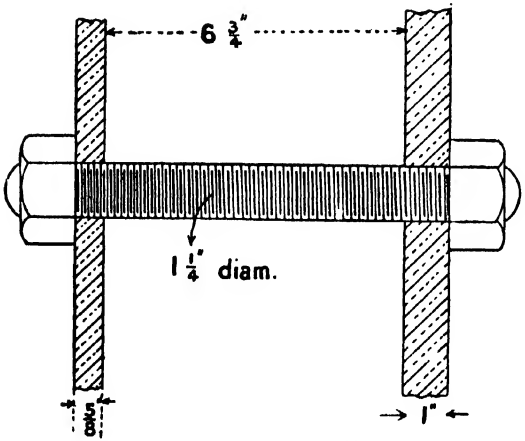


FIG. 87.—Screwed Stay.

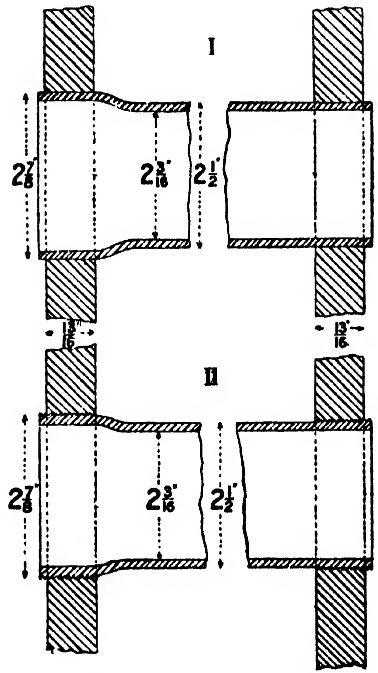


FIG. 88.—Stay Tubes.

Stay tubes. These stay tubes were formerly made of brass, but are now made of mild steel. The *plain tube* **I** (Fig. 88) is $2\frac{1}{2}''$ external diameter. It is made to fit well in the hole of the tube plate, and is rolled or expanded by a tube expander to prevent leakage. The tube is slightly enlarged at the smoke box end to

facilitate insertion or withdrawal. The *stay tube* **II** is thickened at the ends to allow for screwing with a raised or plus thread. The threads are of the same pitch, so as to allow the tube to be screwed simultaneously into the two plates. One end is enlarged to enable the smaller end to be passed through the hole in the outer tube plate.

Example. Draw the two views of (*a*) Bar stay, Fig. 85, (*b*) Stay tubes, full size, Fig. 88.

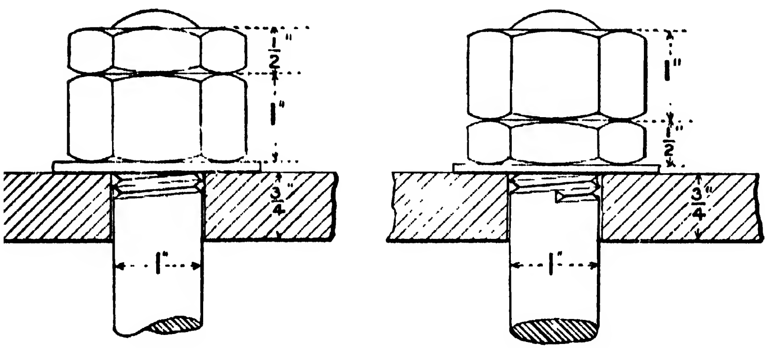


Fig. 89.

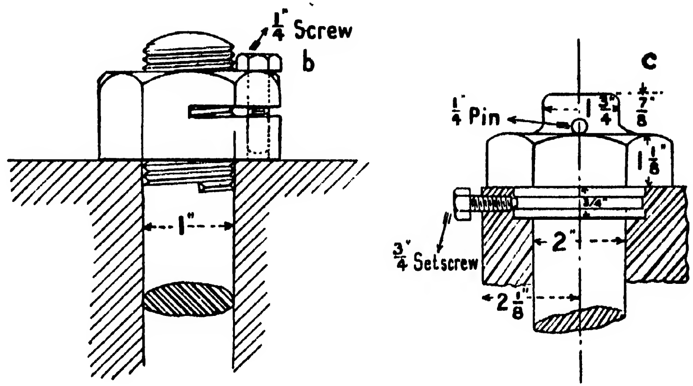


Fig. 90.—Locking Arrangements.

Locking arrangements. There is always a tendency for the nuts of the moving parts in a machine to unscrew owing to the vibration. Several methods have been devised to prevent this, and some of those in general use are indicated in Figs. 89, 90, 91. One of the most common is by means of two nuts (Fig. 89). The first nut is screwed up as tight as is necessary, and the outer nut is brought into contact with it. Finally, whilst the upper one is held firmly by a spanner, the lower one is turned in a backward direction through a short distance, so that the two nuts are firmly wedged together.

The usual arrangement is to place the thicker nut below and the thinner one above. This arrangement allows an ordinary spanner, which is usually thicker than the thinner nut, to be used. A better plan would be to place the thicker nut on the outside. A plan sometimes adopted is to increase the length of the bolt and to use two nuts of ordinary thickness.

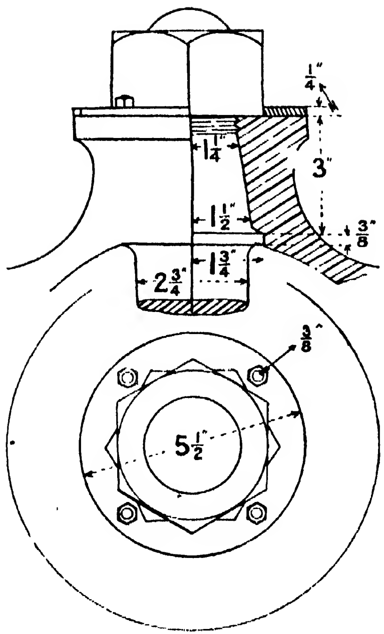


Fig. 91.—Locking Arrangement for Piston Rod.

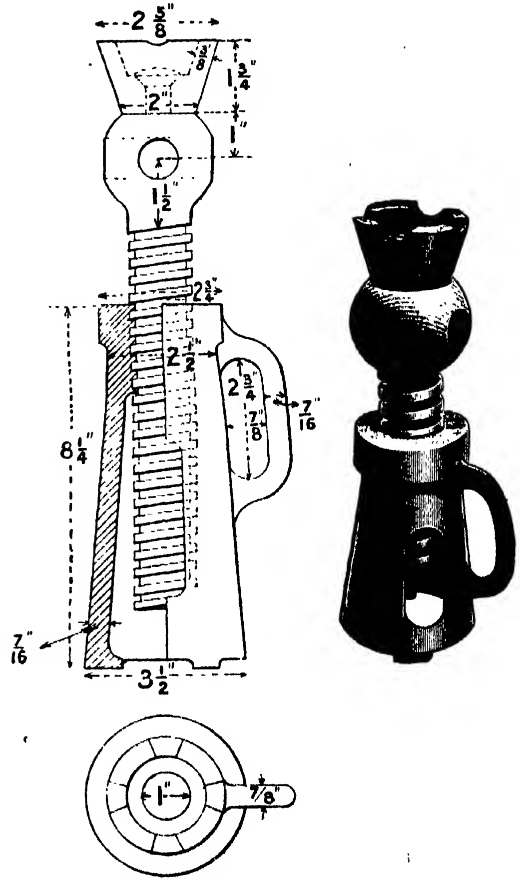


Fig. 92.—2-ton Screw Jack.

Two arrangements sometimes adopted for comparatively large nuts are shown at (b) and (c) (Fig. 90). In that indicated at (c), the lower part of the nut is made cylindrical and can be locked in any position by means of a small set screw.

A simple arrangement consists of a small split pin inserted near the end of the bolt immediately above the nut, as in Fig. 106, p. 77. The disadvantage of such an arrangement is that the nut must remain always in the same position.

A plan frequently adopted is to place what is called a *guard plate* in the space between two or more nuts. The plate is kept in position by one or more small set screws, and these, together with the plate, must be removed before rotation of the nuts can take place. One arrangement of this kind adopted in recent practice for marine pistons is shown in Fig. 176. The thickness of the plate varies from $\frac{1}{4}''$ to $\frac{3}{4}''$, according to the size of the nut, and the studs range from $\frac{3}{8}''$ to $\frac{3}{4}''$ diameter.

The nut at the end of a piston rod may be secured by means of a plate. This plate is fastened by two or more studs and nuts. To tighten the nut, the plate is removed, and may be replaced when the nut is rotated through one-twelfth of a revolution. The arrangement is shown in Fig. 91.

Example. Draw full size the locking arrangement at the end of a piston rod (Fig. 91).

Spring washers. Split washers of various kind are in use. These washers are bent out of shape, and require considerable force to straighten them. One of these placed underneath a nut not only offers resistance due to compression during the tightening of the nut, but, in addition, if any tendency to unscrew occurs, the sharp end of the cut portion of the washer enters the undersurface of the nut and effectually prevents rotation.

Example. 2 ton screw jack. Draw the two views (Fig. 92). Scale full size. Also draw an end view, diameter of screw $1\frac{1}{2}''$, 3 threads per inch.

Example. Complete two views of the studs and tap bolts shown (Figs. 78, 79, 80). In each case draw a plan. Scale full size. What is the advantage of having square necks on the studs in Figs. 79, 80?

Example. Draw the two ends of a stay bolt (Fig. 85). Scale half size. Also draw an end view and a plan.

Example. Draw full size one end of a condenser tube (Fig. 86).

Example. Draw full size the two views of a spanner (Fig. 93).

Example. Girder stay for a boiler. Draw half size (Fig. 94).

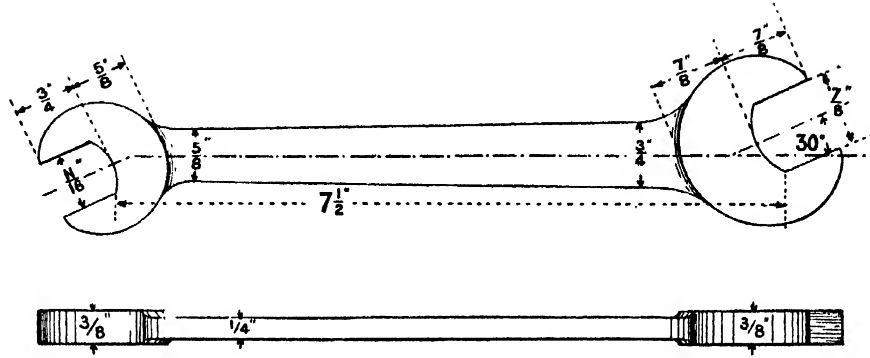


FIG. 93.—Spanner.

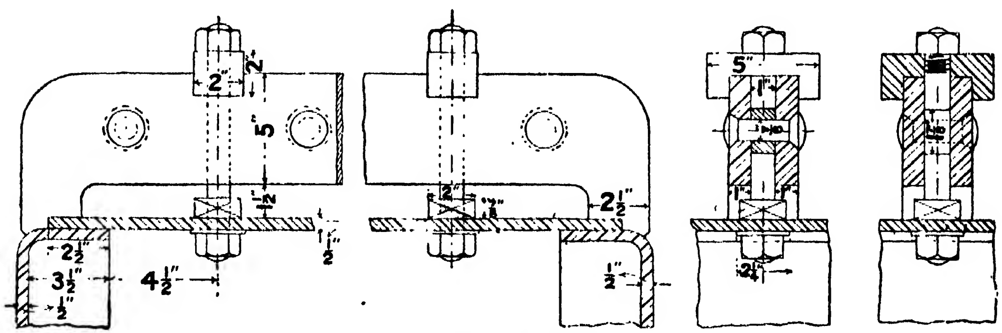


FIG. 94.—Girder Stay.

Knuckle joint. What is called a knuckle joint is shown in Fig. 95. The proportional unit is **d**, the diameter of the pin. When this is known or assumed the remaining proportions can be obtained.

Example. Draw full size the two views of a knuckle joint (Fig. 95). Also draw a plan.

PROPORTIONS OF KNUCKLE JOINTS.

Let **D** denote the diameter of the rod.

Width of rod,	$R = 1\frac{1}{8}D$.
Thickness of forks,	$T = \frac{3}{4}D$, $T_1 = \frac{5}{8}D$.
Width between forks,	$W = 1\frac{1}{4}D$.
Diameter of bosses	$B = 2D$.
" " pin,	$d = D$.
" " pin head,	$D_1 = 1\frac{1}{2}D$.
Thickness of pin head,	$t = \frac{3}{8}D$.
Diameter of collar,	$C = 1\frac{1}{2}D$.

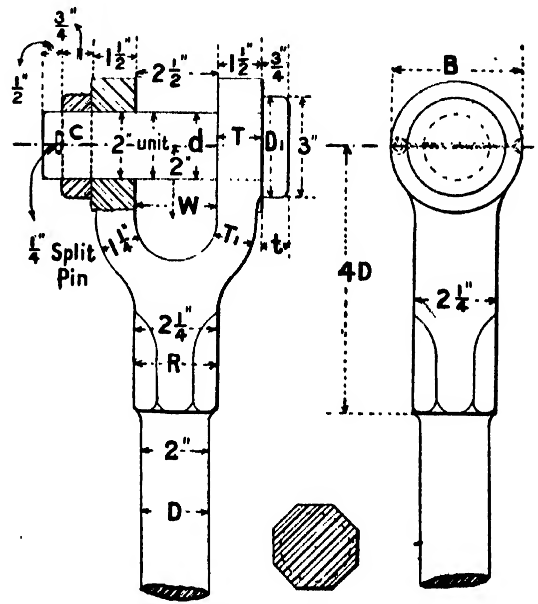


FIG. 95.—Knuckle Joint.

Example. Calculate from the above table the dimensions of a knuckle joint for rods $1\frac{1}{2}''$ diam. Draw sectional elevation, end view, and plan. Full size.

Cotter joints for tie rods. A form of joint suitable for tie rods is shown in Fig. 96. The ends of the tie rods pass into a sleeve and are fastened by cotters. The proportional unit adopted is usually **d**, the diameter of the rod.

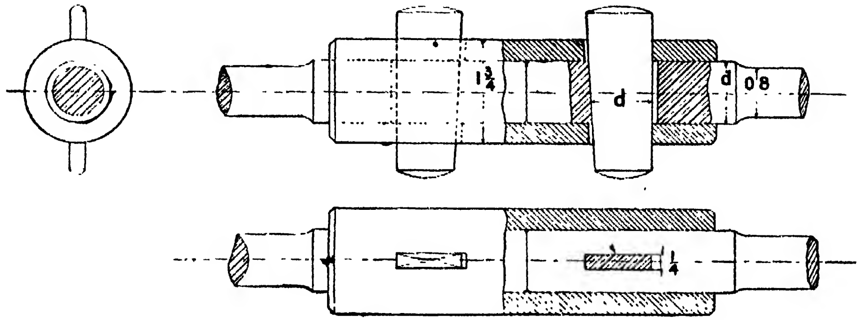


Fig. 96.—Cotter Joint.

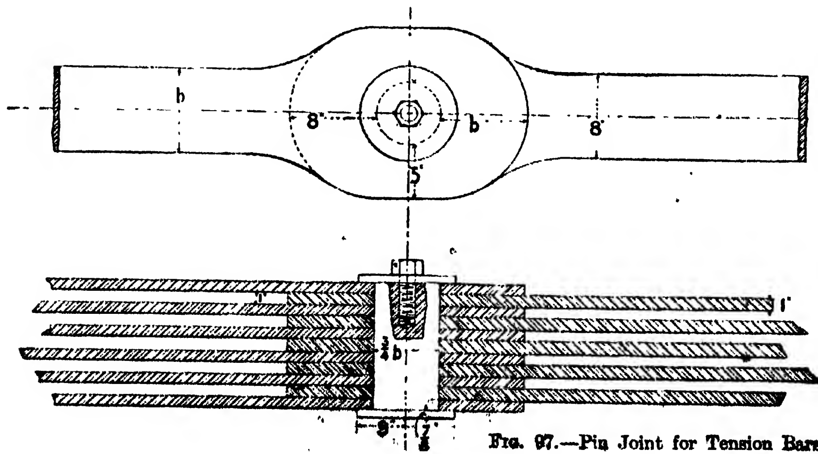


Fig. 97.—Pin Joint for Tension Bars.

Example. Assuming the diameter of each of two tie rods to be 2″, calculate the various sizes and draw the joint. Scale full size.

Pin joint for tension bars. A joint which may be used to connect together a series of tension bars (as in the links of the chain of a suspension bridge) is indicated in Fig. 97. The ends of the bars are enlarged as shown. The proportional unit is b, the breadth of each tie bar.

Example. Assuming the breadth of the tie bars to be 8″ and thickness 1″, calculate suitable dimensions and draw the two views of the joint (Fig. 97). Scale $\frac{1}{4}$.

EXERCISES. III.

1. Sketch a bolt with a square head, and a hexagonal nut. Supposing the bolt to be 1″ in diameter, mark the usual dimensions of the nut and bolt head. How many threads to the inch are used on an inch bolt?

2. Make a sketch of a stud. Describe how it is screwed into place and state any circumstances in which it may be used in preference to a bolt. [B.E.]

3. Sketch the profiles of the various forms of screw threads commonly employed in machinery giving the proportions adopted. Point out the relative merits of the various forms.
State the advantage due to the use of a hexagonal nut as compared with a square one.

4. Sketch a form of bolt used for securing a machine to a stone foundation, and explain how the bolt is fixed in the stone. [B.E.]

5. Show by sketches the various forms of bolts, studs, screws and nuts which are commonly employed in securing together the parts of a machine.

6. Sketch the end of a foundation bolt, showing how to fix it by a cotter and cast-iron plate below the masonry.

7. Draw full size (i) a Tee head bolt, (ii) Hook bolt, (iii) Eye bolt, (iv) Rag bolt, (v) Lewis bolt, (vi) Cotter bolt. Diameter of bolt $\frac{7}{8}$″.
Give any example in which each may be used.

8. Draw, full size, about 4 turns of a square thread for a screw of $1\frac{1}{2}$″ pitch; outside diameter of thread 4″, inside diameter $2\frac{1}{2}$″.

9. A rectangular water tank is built up of flanged cast-iron plates. Sketch a form of joint at one corner where three plates meet.

10. Show, by sketches, Whitworth's and Seller's standard forms of screw threads. Assuming a pitch of 1″, put on your sketches the remaining dimensions.

11. Sketch two or three methods which are in use to prevent a nut working loose.

12. Select a special example of each of the following two kinds of fastenings. Sketch the forms of the fastenings and the forms of the pieces united in the locality of the fastening, for each state the reasons which cause that form of fastening to be preferred to the other.

(*a*) A rivet. (*b*) A bolt. [B.E.]

13. Give an example of the use of both a right and left handed screw thread on the same piece and describe how it is used.

14. Show the form of the Whitworth screw thread by drawing a section on one side of a screwed rod for a length of two inches. Draw five times full size, using a pitch of $\frac{1}{4}$″. [B.E.]

15. Describe with sketches some form of spanner which is adjustable to fit various sizes of nuts. [B.E.]

16. Sketch and describe how the flat end plate of a boiler is strengthened by the use of a longitudinal bar stay.

17. Point out the various ways in which a screwed bolt and nut may yield to the forces to which they are subjected.

18. The cover of a hydraulic cylinder is secured by two bolts. If the water pressure is 700 lbs. per sq. inch, and the cylinder $1\frac{3}{4}$ in. diameter, find the diameter of the bolts. Safe stress 3000 lbs. per sq. in.

19. Find the diameter of the screwed end of a piston rod, diameter of the cylinder 20 in., pressure of steam 80 lbs. per sq. in. Safe stress, 6000 lbs per sq. in.

Give dimensioned sketches of the nut.

20. The longitudinal bar stays of a short boiler are 16 inches apart, horizontally and vertically. The steam pressure is 135 lbs. per sq. in. Find the diameter, the material being mild steel. Safe stress, 8000 lbs. per sq. in.

21. The chain of a suspension bridge is made up of links having a rectangular cross section 6″ by 1″. Sketch with dimensions a pin joint suitable for connecting the links.

22. Give dimensioned sketches of a knuckle or fork joint suitable for connecting two rods 1″ diameter.

23. A tie rod of $1\frac{1}{4}''$ round iron is made in two lengths, connected by a sleeve and two steel cotters, the rod ends at the junction being enlarged. Sketch the joint and insert suitable dimensions.

24. If d is the diameter of a bolt, p the pitch of the screw thread, n the number of threads per inch, and d the diameter at the bottom of the thread, calculate values of p, n, and d, when $d = 1''$, $1\frac{1}{2}''$, $2\frac{1}{2}''$, $3''$.

(i) Vee thread $p = 0{\cdot}08d + 0{\cdot}045$, $d_1 = 0{\cdot}845d$.

(ii) Square thread $p = 0{\cdot}16d + 0{\cdot}9$, $d_1 = d - p$, $n = 1 \div p$.

25. Find the diameter of the screwed stays, each of which supports an area of the flat surface in a boiler equal to a square of 4″ side, steam pressure 150 lbs. per sq. in., safe strength of the material 4000 lbs. per sq. in.

26. A flat surface in a marine boiler is constructed of $\frac{5}{8}''$ plates, with wrought iron stays 6″ apart, steam pressure 120 lbs. per sq. in. Show how to fix the stays. Also determine their diameter. Safe stress 4000 lbs. per sq. in.

27. The square thread in a screw jack is $1\frac{1}{2}''$ diameter, pitch $\frac{1}{3}''$ (p. 61). If the safe stress is 4000 lbs. per sq. in., find the load that can be raised.

28. A cylinder is 12 in. diameter, pressure of steam 100 lbs. per sq. in. Find the diameter of the bolts in the cylinder cover if 12 bolts are used. Safe stress 3000 lbs. per sq. in.

CHAPTER IV.

SHAFTING, KEYS AND COUPLINGS.

Keys. What are known as *keys* consist either of wedge-shaped, or parallel, pieces of wrought iron, or steel. They are used to connect rigidly wheels, cranks, pulleys, etc., to shafts. Several forms of keys in general use are shown at (a), (b), (c), (d) and (e) in Fig. 98. In each case one end of the key called the

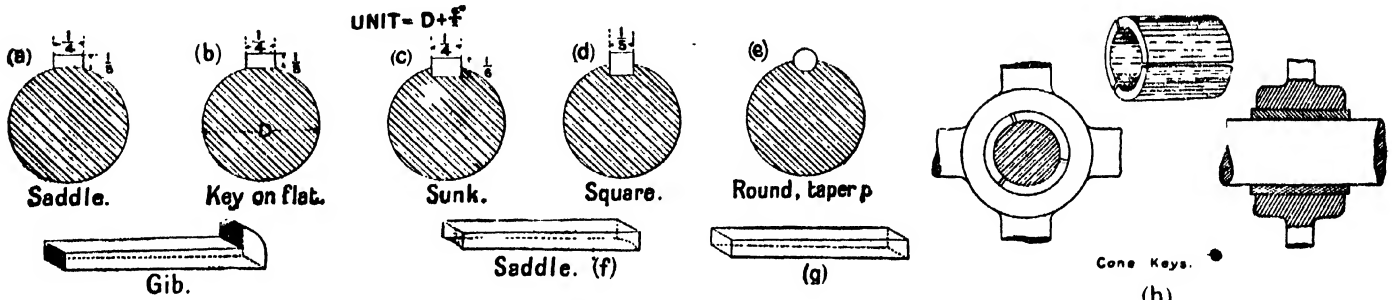


FIG. 98.

head is made slightly thicker than the opposite end, called the *point of the key.* When driven into suitable grooves in a wheel, or in a pulley, the friction set up forms a rigid connection between the pieces joined, and rotation of one ensures the rotation of the other. The resistance thus offered to slipping depends to some extent upon the shape of the key and the surface on which it rests. Thus, when the resistances to motion are comparatively small, as in light pulleys and wheels, what is known as **a saddle key** (Fig. 98 (a)) may be used. The under surface of a saddle key is made hollow to fit the shaft, and in this manner a wheel, or pulley, can be fixed in any desired position along a shaft.

The resistance to slipping is increased when the under surface of the key (b) is flat. The most secure form of key is that at (c), called a *sunk key*, in which one-half the key is sunk in the shaft and the remaining half in the wheel or pulley.

In certain cases, as in some machine tools, a square key, as at (e) (Fig. 98), is used. Such a key is parallel from end to end, and some means must be adopted to prevent the key moving in an endlong direction during the rotation of the shaft. In many cases this endlong motion is prevented by a thin plate, or washer, fastened by a set screw to the end of the shaft.

Proportions of keys. When the diameter of a shaft is known, it is important to be able to insert the dimensions of a suitable key. These dimensions may be obtained by calculation; or an empirical rule, such as the following, may be used and should be committed to memory.

The proportional unit is obtained first by adding $\frac{1}{2}''$ to the diameter of the shaft. The breadth and depth of the key are then expressed as fractional parts of the unit, as follows:

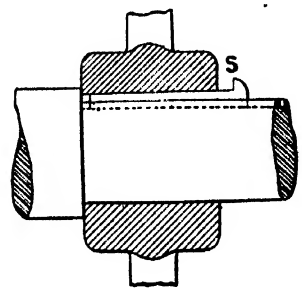
Saddle and key on flat: breadth $\frac{1}{4}$, depth $\frac{1}{8}$.
Sunk key: breadth $\frac{1}{4}$, depth $\frac{1}{6}$.

The practical method is to increase the diameter of the shaft by half an inch on the same scale as that to which the shaft has been drawn and then to take $\frac{1}{4}$, and $\frac{1}{8}$ or $\frac{1}{6}$th of the distance so obtained.

Example. Find the dimensions of the key for a shaft $3\frac{1}{2}''$ diameter (a) for a saddle, or key on flat, (b) for a sunk key.

Adding $\frac{1}{2}''$ to the given diameter the unit becomes $4''$.

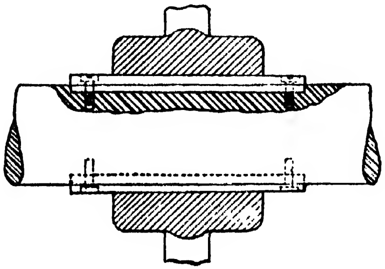
$\therefore$ (a) $= 1''$ and $\frac{1}{2}''$, (b) $= 1''$ and $\frac{2}{3}''$ are the breadth and depth respectively.



Gib Key.
FIG. 99.

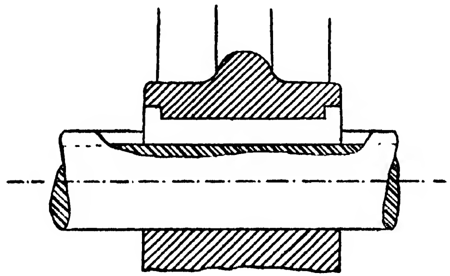
Gib key. To dislodge a key of the form shown at (f) and (g) (Fig. 98) it is necessary to be able to drive it in a backward direction from the point end of the key. In some cases, a projection on the shaft may occur as at (Fig. 99), and the point of the key is inaccessible. In such circumstances what is called a *gib key* may be used, since this form of key may be released, if necessary, by inserting a wedge in the space marked S.

Sliding keys. A wheel, or pulley, is sometimes required not only to turn with the shaft, but also to slide in the direction of the length of the shaft. In such a case the key is made parallel and may be square in cross-section as at (d) (Fig. 98). Such a key may be fastened to the shaft by means of small set screws, as indicated in Fig. 100. Another arrangement is shown in Fig. 101, in which the key is secured to the wheel, or pulley.



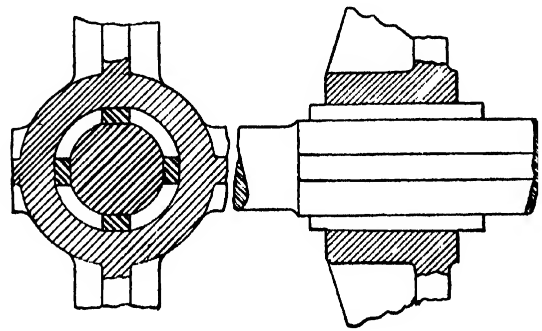
Sliding Keys.

FIG. 100.



Key fixed to Wheel.

FIG. 101.



Staking on.

FIG. 102.

Staking on. In the case of large wheels and pulleys the hole is sometimes made larger than the diameter of the shaft, and the two are fastened together by four taper keys (Fig. 102)—a process known as *staking on.*

Taper of a key. The taper of a key varies from $\frac{1}{8}''$ to $\frac{3}{16}''$ per foot of its length. Usually the former fraction corresponding to a taper of 1 in 96 is used.

Cone keys. To enable a wheel, or pulley, to pass over projections such as collars, etc., on a shaft, the hole is made larger than the shaft, and also what are known as *cone keys* are inserted in the space between the shaft and the pulley. Cone keys are usually made of cast iron and are cast in the form of a hollow cylinder; the inner surface is bored to fit the shaft and the outside is made of a taper or conical form to fit the hole in the pulley, or wheel. When this has been done, the casting is divided into three

or four equal portions, as in *Fig.* 98A. The pulley, or wheel, is secured to the shaft by driving these cone keys firmly into place.

In another arrangement, a screw thread is formed on the outside of the cone keys and a similar thread on the inner surface of the wheel, or pulley. Holding the cone keys at rest, the pulley is screwed as tightly as is necessary to secure it firmly to the shaft. The direction of rotation is such that the resistance of the belt on the pulley tends still further to increase the grip.

Shafting. The material generally used for shafting is either wrought iron or mild steel. Cast iron is rarely, if ever, employed for such a purpose. The cross-section is usually circular. Exceptions are furnished by such special cases as the shafting used in some overhead travelling cranes in which square shafting is used.

The strength of a circular shaft to transmit force depends upon the cube of its diameter. Thus, the strength of two shafts of the same material, and 2″ and 3″ diameter respectively, would be proportional to the numbers 8 and 27, or as 1 to 3·4. Whilst the weights of equal lengths of the two shafts would be proportional to the squares of the diameters, or as 4 to 9, or nearly 1 to 2. Hence, in large marine shafts, the weight of a given length of shafting being retained, its strength may be increased considerably by making the shaft hollow. Thus, for example, a hollow shaft in which the external diameter is 25″ and the internal diameter 14″, would weigh about the same as a solid shaft $20\frac{3}{4}$″ diameter, but would have about double the strength.

The **torsional strength of a circular solid shaft** is given by

$$T = \frac{\pi}{16} f d^3, \quad \text{(i)}$$

where T is the twisting moment in lbs. inches, d is the diameter of the shaft in inches, and f is a constant depending upon the material of the shaft. Thus, f for wrought iron is usually taken to be about 9000 lbs. per sq. in. and f for steel about 13,500 lbs. per sq. in.

In the case of a hollow steel shaft, of external diameter D, and of internal diameter d, the formula becomes

$$T = \frac{\pi}{16} f \left(\frac{D^4 - d^4}{D}\right), \quad \text{(ii)}$$

where f has the same value as before.

When the numerical value of T is known, the diameter of a shaft may be obtained from (i) or (ii).

The twisting moment that can be transmitted safely by a shaft of diameter d, or diameters D and d, can be obtained easily by calculation from (i) or (ii).

If l is the length, and b the width of a key, then if l is known, b can be found from

$$lbf \times \frac{d}{2} = \frac{\pi}{16} d^3 f.$$

For convenience in handling and in manufacture, shafts used in factories, and for similar purposes, are made in convenient lengths of from 20 to 30 feet. These separate lengths are connected by means of suitable couplings. These couplings, may, as in marine shafts, be made in one piece with the shaft, or are made separately and afterwards fastened to the shafts by means of keys.

Shaft couplings. The couplings used in connecting together lengths of shafting may be divided roughly into two classes, viz.: *fast*, and *loose or disengaging* couplings. Of the fast couplings, the shafts, except in cases of renewal or repair, rarely require to be disconnected. The couplings in general use are known as *box or muff*, *half-lap*, and *flange* couplings.

Loose or disengaging couplings are of many different forms. Thus, one coupling may be provided with projections fitting into corresponding recesses of the other (Fig. 107, p. 78). Such couplings are very suitable for slowly moving shafts; but for shafts moving more quickly some form of friction coupling is used. In one form, the wedging action between two conical surfaces, which may be forced together or released, is employed. In another form a split ring is placed inside another ring, the two open ends of the ring are forced apart or released by means of a wedge actuated by a screw. When the wedge is forced into place, the two parts of the coupling, due to the expansion of the ring, are held together firmly without slipping, and rotation of one shaft ensures the rotation of the other. When the wedge is withdrawn, the split ring, which is fastened to one shaft, rotates freely without giving motion to the other.

Box or muff coupling. A *box* or *muff coupling* is shown in Fig. 103. It consists of a cast-iron box B, in the centre of which the two shafts S_1 and S_2 meet. The coupling is fixed usually by passing the box over the end of one shaft as S_1, and placing the other shaft in position. Then, drawing back the coupling until the centre of the coupling coincides with the ends of the two shafts, a sunk key is used generally to fasten each end of the shaft to the coupling.

It will be seen from Fig. 103 that the point end of one key is not in contact with the head of the other, but the two are separated by a short interval. This device enables the first key to be released and

used as a driver to release the second key. In this manner the loosening and removal of the keys are facilitated.

In some cases only one key is used, and this is the full length of the coupling. This arrangement requires that the key ways in the ends of the two shafts shall be exactly the same depth, and is therefore not so good an arrangement as the preceding one.

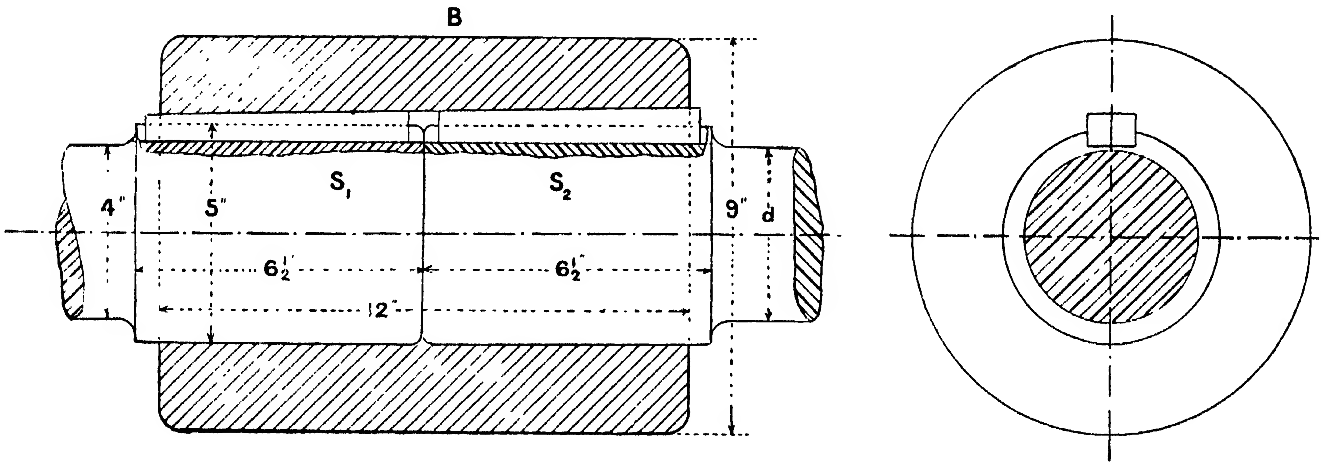


FIG. 103.—Box or Muff Coupling.

The following proportions may be used to determine the dimensions of a box coupling:

Length of coupling = 3d
Diameter ,, $= 2\frac{1}{4}$d
Diameter of enlarged portion of shaft $= 1\frac{1}{4}$d,

where d denotes the diameter of the shaft.

The following table gives some dimensions of couplings suitable for shafts up to 5″ diameter:

BOX OR MUFF COUPLINGS.

Diameter of shaft,	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5
" " coupling,	$4\frac{1}{2}$	$5\frac{5}{8}$	$6\frac{3}{4}$	$7\frac{7}{8}$	9	$10\frac{1}{8}$	$11\frac{1}{4}$
Length of coupling,	6	$7\frac{1}{2}$	9	$10\frac{1}{2}$	12	$13\frac{1}{2}$	15

Example. Draw half size the two views of a box coupling (Fig. 103). Also draw a plan.

Half-lap coupling. In the *half-lap coupling*, introduced by Sir William Fairbairn, the two ends of the shafts are made to overlap each other and are usually fastened by a key as in Fig. 104. In this way the taper of the half lap prevents the separation of the two shafts due to any pull in the direction of the length of a shaft. The taper is about 1″ per foot or 1 in 12. Couplings of this kind are expensive to make and are therefore not often used.

The dimensions of a half-lap coupling for a given diameter d of shaft may be obtained from the following proportions:

Length of coupling $=2d$. Diameter of coupling $=2\frac{1}{4}d$. Diameter of enlarged part of shaft $=1\frac{1}{4}d$.

Oldham's Coupling, Fig. 104*a*, may be used when the axes of the shafts are parallel, but not in the same straight line. A flange F with two projecting pieces at right angles to one another, fit recesses in the flanges on the shafts. Draw half size.

Example. Draw half size the two views of a half-lap coupling (Fig. 104). Also draw a plan.

Flange couplings. A flange coupling, or a *face plate coupling*, is usually made of cast iron. The halves of the coupling are turned in the lathe, the holes bored to fit the shafts, and the key-ways cut

The parts are then keyed to the shafts, the head of the key in each case being at the end of the shaft. When this has been done, each shaft is again put into the lathe centres and the two faces of the coupling, which fit together, are made perpendicular to the axis of the shaft. The rotation of the bolts during the process of turning the nuts is prevented by making the bolts fit the holes in the flanges somewhat tightly; or, a small pin or snug may be inserted close to the head of the bolt for the same purpose.

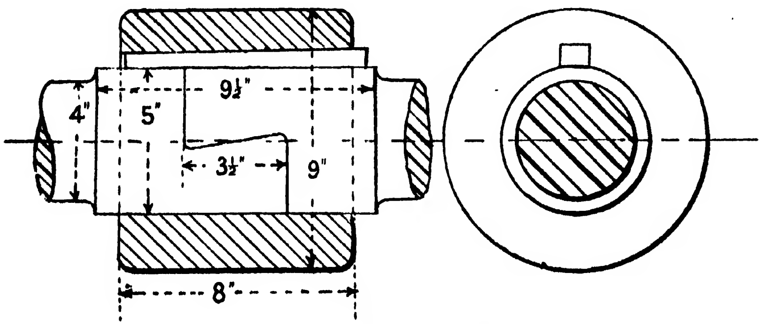


FIG. 104.—Half-lap Coupling.

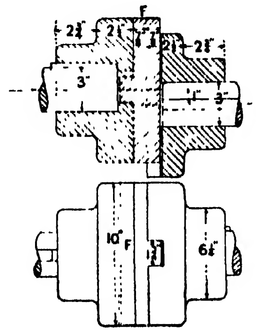


FIG. 104A.—Oldham's Coupling.

One coupling is made to enter a short distance, $\frac{1}{4}''$ or $\frac{3}{8}''$, into the other. This plan ensures that the couplings are in line with each other. When necessary the flanges of the couplings are made of sufficient thickness to allow recesses to be formed for the bolt heads and the nuts as in Fig. 108.

The dimensions of a *flange coupling* for shafts of diameter d may be found from the following:

Diameter of boss $= 2d$, thickness of flange $= \frac{1}{2}d$

Length of flange and boss $= 1\frac{3}{4}d$.

Example. Draw half size the two views of a flange coupling (Fig. 105). Also draw a plan.

Coupling for marine shafts. In the shafts for marine engines, the flanges are usually forged in one piece with the shaft and are secured by bolts. For this purpose taper bolts—which are made to fit the holes—are employed. The number of bolts used is generally 6, 8, 9, or 12. The various lengths of

shafting are filleted into one another to keep them in line, or the flanges are each recessed to an equal depth to receive a steel disc. The bolts are made with heads, as shown in Fig. 106, and often without heads. The following table gives particulars of some couplings taken from actual practice (the dimensions are in inches):

MARINE FLANGE COUPLINGS.

Diameter of shaft	6	$9\frac{1}{4}$	$16\frac{1}{2}$	$22\frac{1}{2}$	23
Diameter of flange	$12\frac{3}{4}$	19	32	35	38
Thickness of flange	$1\frac{3}{4}$	$2\frac{3}{4}$	$4\frac{1}{4}$	6	5
Diameter of bolt circle	$9\frac{1}{2}$	$14\frac{1}{8}$	25	$28\frac{3}{4}$	$30\frac{3}{8}$
Number of bolts	6	6	8	9	8
Diameter of bolts	$1\frac{5}{8}$	$2\frac{3}{4}$	$3\frac{1}{2}$	$4\frac{1}{4}$	$4\frac{1}{4}$

Example. Draw two views, half sectional elevation and end view of the coupling (Fig. 106). Scale half size. Also draw a plan.

Example. Draw two views of a coupling for a marine shaft $16\frac{1}{2}''$ diameter, from the data in the preceding table.

Claw, or disengaging coupling. In the forms of couplings, shown in Fig. 107, one half the coupling is fastened to one shaft S_1 by means of a *sunk key*; the other part **D** is connected to the shaft S_2 by means of a *sliding key*. By means of a suitable lever, centred outside the axis of the shaft and having one end in the recess **A**, the coupling **D** can be brought into contact with, or moved away from, the part **B**. As the shaft S_2 is

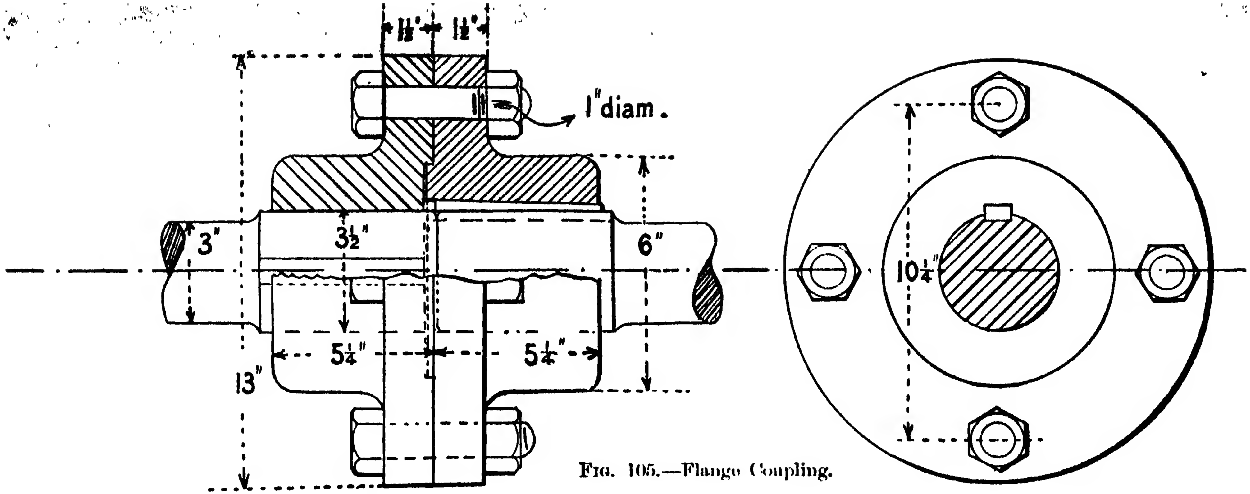
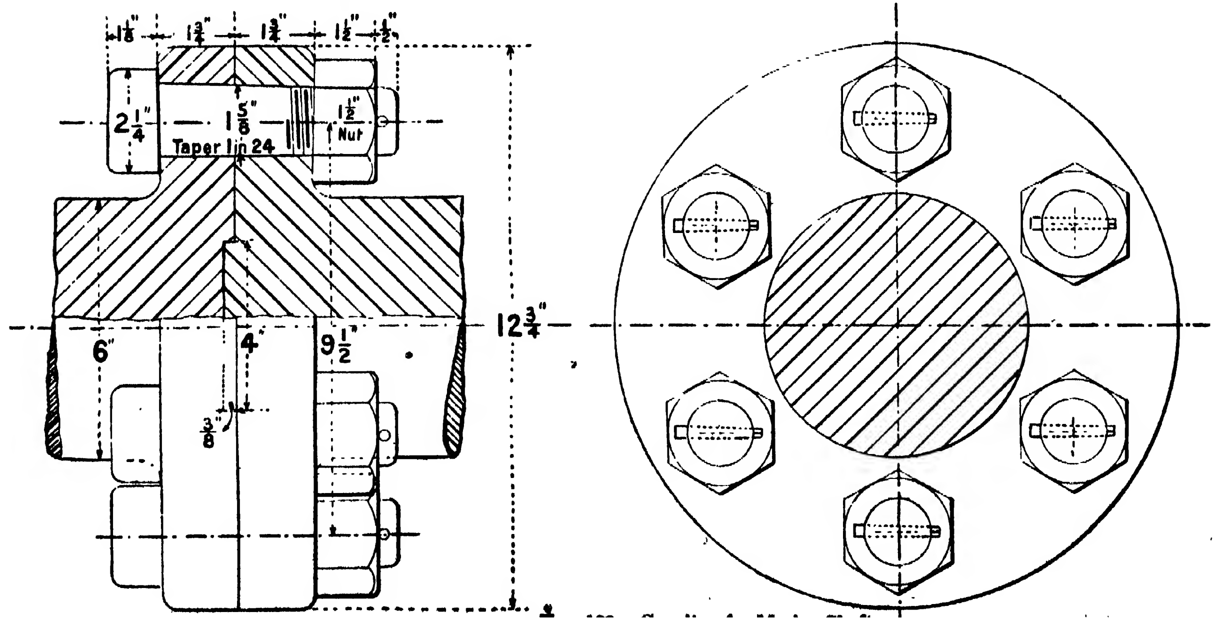


Fig. 105.—Flange Coupling.



the driver it follows that when the two couplings are in gear, the shaft to which **B** is fastened will rotate, but when **D** is drawn out of gear with **B**, then **B** will remain at rest.

Example. Draw the disengaging coupling (Fig. 107). Scale half size.

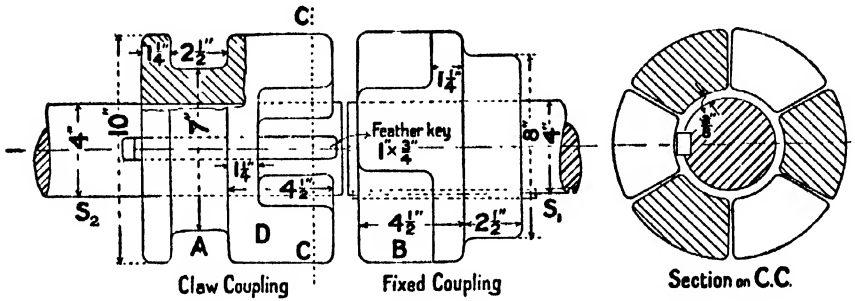


FIG. 107.—Disengaging Coupling.

Friction cone coupling. This coupling (Fig 108) closely resembles externally a flange coupling. The cone keys are bored to fit the shaft and the outside turned taper to fit corresponding holes in the two couplings. When the halves of the coupling are drawn together by means of the bolts, the sloping surfaces of the cone keys will force these very tightly against the shaft, and in this manner rotation of one ensures the rotation of the other.

Hooke's Joint or Universal Coupling is used to connect two shafts the axes of which intersect; it has the advantage that the angle between the shafts may alter while they are in motion (Fig. 108A).

Example. Draw half size the sectional elevation and end view of the coupling in Fig. 108.

Flexible coupling. In the preceding types of coupling the object throughout has been to obtain rigidity; the turning of one shaft must give the same definite motion to the other; in other words, no yielding or slipping of the couplings is supposed to occur. There are many other cases to consider in machinery, especially where sudden shocks, or where twisting forces, are suddenly applied (which tend to fracture a shaft). In such cases the shaft must be sufficiently rigid to transmit the force required, and

must also be flexible enough to yield to any sudden shock without fracture. Such a coupling is known as a *flexible coupling*, and may consist of two parts resembling a flange coupling, one half rigidly fastened to one shaft and the other half to the other shaft. But the two halves, instead of being fixed together by

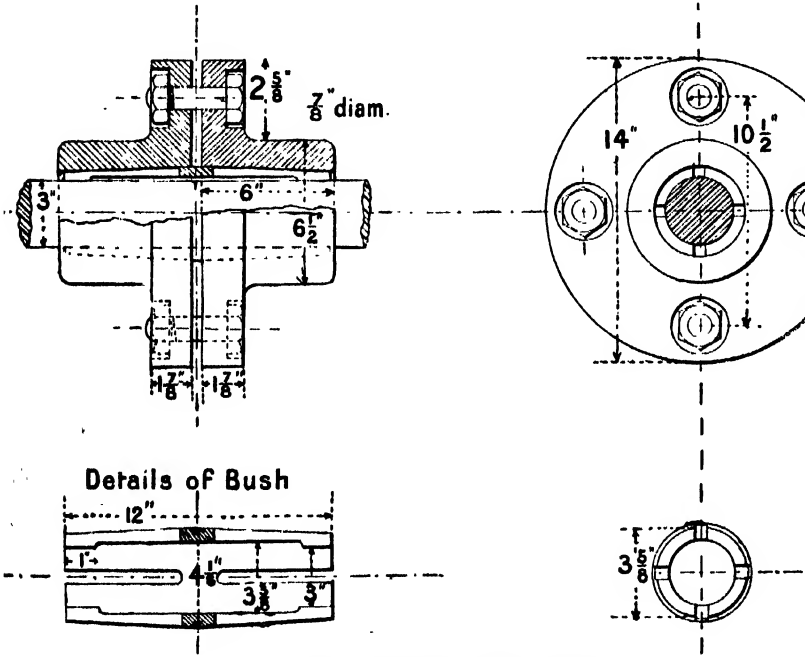


Fig. 108.—Friction Cone Coupling.

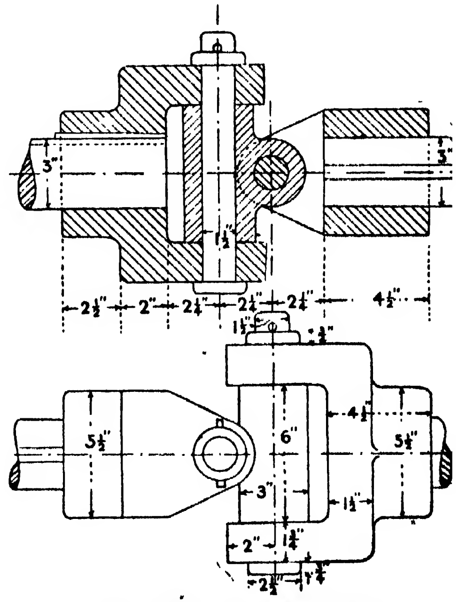


Fig. 108A.—Universal Coupling.

a rigid bolt connection, are connected by steel springs, as in Perry's Transmission Dynamometer, or by a disc or ring of leather, as in Fig. 109, where, as shown by a zig-zag section, a ring of leather L is fastened by means of 6 screws to the coupling A and also to the coupling B. In such an arrangement any sudden twisting action is allowed for by the flexibility of the steel springs, or the leather.

Example. Draw half size the two views of the flexible coupling (Fig. 109).

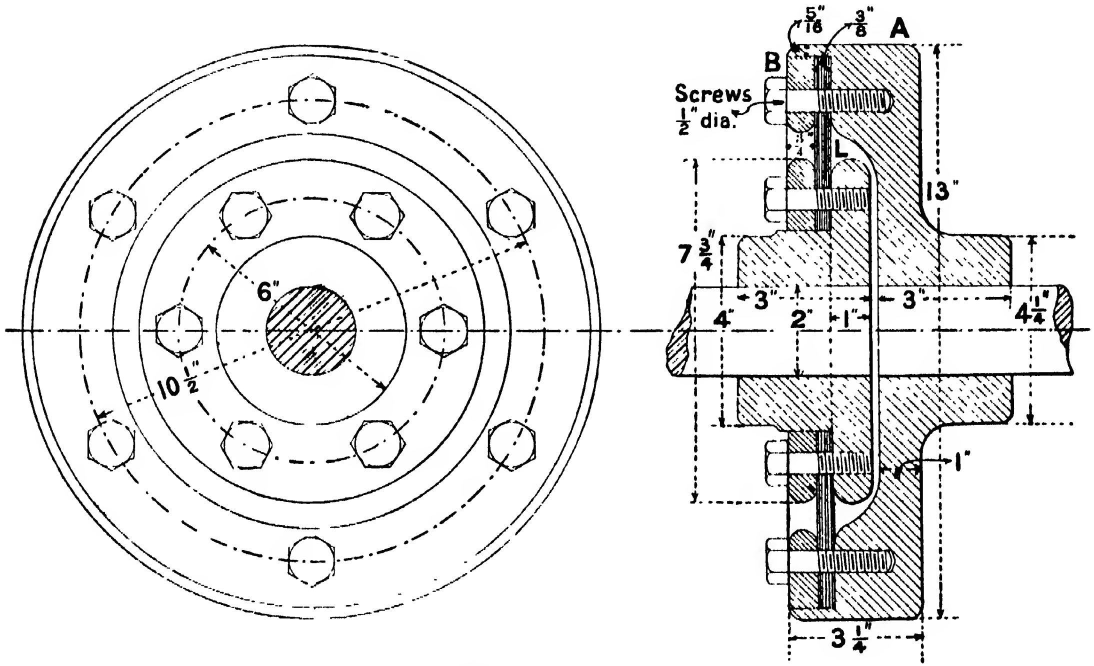


FIG. 109.—Flexible Coupling.

EXERCISES. IV.

1. Show by sketches some of the various methods of fitting a key to prevent relative rotation of a shaft and a piece which is mounted on it. Quote an example of the use of each method of fitting, mentioning the difference in the circumstances of each.

2. Describe a coupling for shafting on which there are no projecting bolt heads, nuts, or key heads. [B.E.]

3. Of what material is shafting usually made. Show by means of a sketch the usual form of shaft neck or journal. Explain the use of loose collars.

4. In some forms of flange couplings the bolt heads and nuts are placed in circular recesses to avoid projections. Sketch some form of box-key or spanner which may be used for tightening the bolts.

5. Sketch two or three forms of coupling suitable for mill shafting.

6. What is the object of using cone keys for fastening pulleys to shafts?

7. Two shafts of 2″ diameter are connected by a muff or box coupling. Draw section, end view and plan. (Scale half size.)

8. Show by sketches how a wheel is fixed on a shaft by means of a sunk key; also some method by which the key may be withdrawn when it cannot be driven from the point end.

9. Give sketches showing how the separate lengths of a line of shafting may be connected together. [B.E.]

10. Show by sketches a claw or disengaging coupling (or friction clutch). Explain how the coupling is put in and out of gear whilst the shaft is running.

11. Describe with sketches (*a*) how you would proceed to cut a parallel and also a taper key-way in a pulley or wheel; (*b*) how you would proceed to fit such a key; (*c*) state any method of fitting a feather or sliding key so as to permit a pulley or wheel to be moved endways along the shaft.

12. Sketch and explain the modes of fixing a wheel or pulley by means of a saddle key, by cone keys, and by staking on. In each case give suitable dimensions for a shaft $3\frac{1}{2}''$ diameter.

13. Sketch a butt or muff coupling and a half lap and a flange coupling, suitable for a shaft 3″ diam. State any circumstances when one may be used in preference to the others. Insert on the sketch suitable dimensions.

14. With the aid of sketches describe how the following four kinds of fastening are used in connecting together parts of machines—quote one example of each fastening, in which it is preferable to use that kind of fastening rather than one of the others: (*a*) a bolt and nut, (*b*) a rivet, (*c*) a cotter, (*d*) a key. [B.E.]

CHAPTER V.

BELT AND ROPE PULLEYS.

Belt pulleys. If **A** and **B** represent two shafts on each of which a pulley is fastened, then by means of a belt the rotation of one shaft will cause the rotation of the other. If **A** is the *driver* and **B** the pulley driven by it (usually called the *follower*), then when an open belt is used, **B** will rotate in the same direction as **A**, and in the opposite direction when the belt is crossed (Fig. 110). The speed of **B** compared with that of **A** will depend upon the sizes of the pulleys on **A** and **B**.

Let **N** denote the number of revolutions made by **A** in a given time, and **n** the number made by **B** in the same time; also let **D** denote the diameter of the pulley on **A**, and **d** that on **B**.

If no slipping occurs between the belt and the rim of the pulley, the speed of the rim must be the same as that of the belt.

Speed of rim of $\mathbf{A} = \mathbf{D} \times \pi \times \mathbf{N}$, and this must be the same as the speed of **B** or $\mathbf{d} \times \pi \times \mathbf{n}$;

$$\therefore \quad \mathbf{D}\pi\mathbf{N} = \mathbf{d}\pi\mathbf{n}$$

$$\text{or } \frac{\mathbf{n}}{\mathbf{N}} = \frac{\mathbf{D}}{\mathbf{d}} \quad \dots\dots\dots\dots (1)$$

It follows that when the diameters of the pulleys are the same, the number of revolutions of **A** is the same as **B**.

Example. Let the pulley on **A** be 36″ diameter, and make 100 revolutions per minute.

If the pulley on **B** is 12″ diam.,

$$\text{Speed of } \mathbf{B} = \frac{36 \times 100}{12} = 300 \text{ revol. per min.}$$

Length of Belt. A good approximation to the length of belt required may be obtained by graphical construction. Let **A** and **B** (Fig. 110) denote the two pulleys. Draw **CF** the common tangent to the two circles, then one-half the length required is obviously the arc **DC,** the length **CF** and the arc **FE.** Divide the arc **CD** into four equal parts so that **Cb** is $\frac{1}{4}$ **CD.** With **C** as centre and **Cb** as radius, describe an arc cutting **FC** produced in **R.** Then with **R** as centre and **RD** as radius, describe an arc cutting **FC** produced

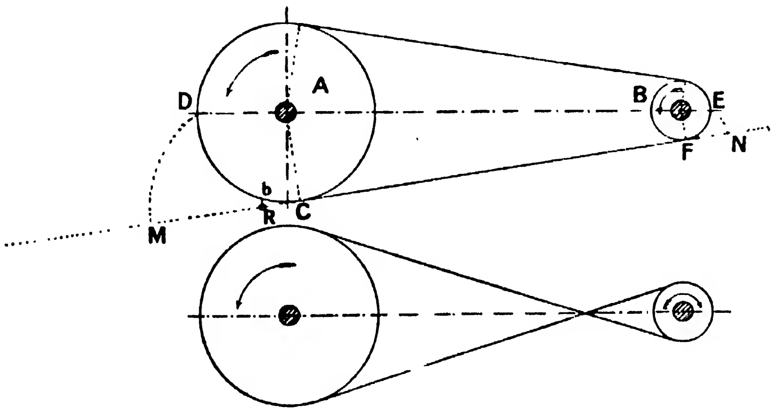


FIG. 110.

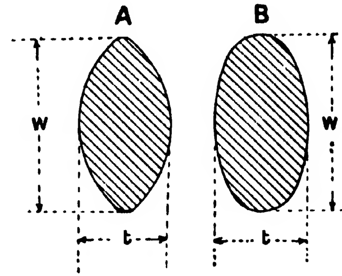
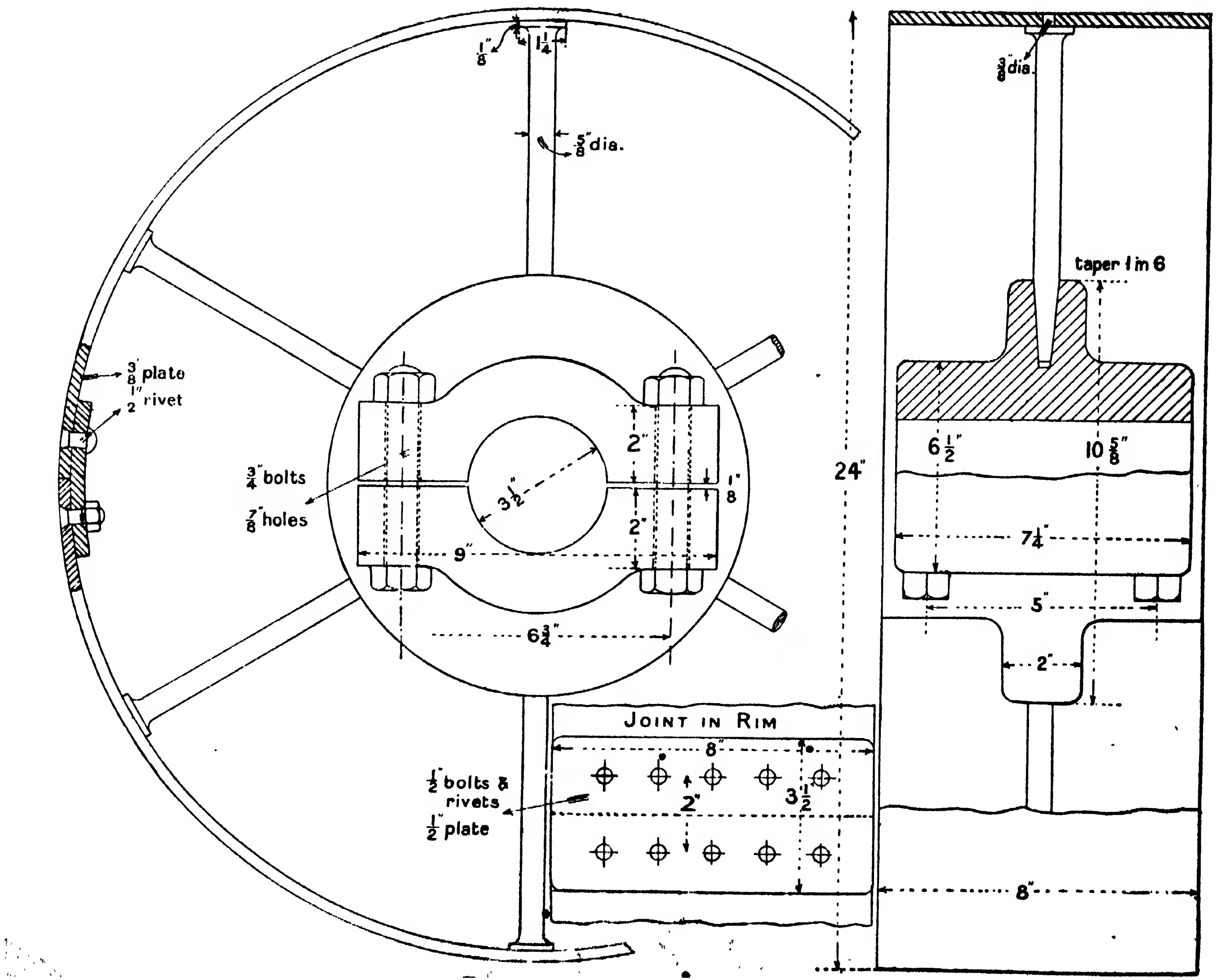


FIG. 111.—Arms of Pulleys.

in **M.** The length **CM** is equal to the arc **CD.** In a similar manner, obtain the point **N.** Then twice the length **MN** is the length of belt required.

Pulleys made of cast iron are commonly used for comparatively low speeds, but this material is not sufficiently trustworthy or safe in the case of high speeds. For such high speeds the boss alone frequently is made of cast iron, the rim and arms are either wrought iron or mild steel. Pulleys made in this manner have less weight than those of cast iron and are more trustworthy.

Arms of pulleys. The arms of pulleys when made of cast iron may be *segmental* as at **A** (Fig. 111), *elliptical* as at **B**, or *cross-shaped* as shown in Fig. 114. The thickness t (Fig. 111) is usually made $\frac{1}{2}$w.



$\frac{1}{8}$"
$1\frac{1}{4}$
$\frac{5}{8}$" dia.
$\frac{3}{8}$" plate
$\frac{1}{2}$" rivet
$\frac{3}{4}$" bolts
$\frac{7}{8}$" holes
2"
$\frac{1}{8}$"
$3\frac{1}{2}$"
9"
$6\frac{3}{4}$"
Joint in Rim
8"
$\frac{1}{2}$" bolts & rivets
$\frac{1}{2}$" plate
$3\frac{1}{2}$"
24"
$\frac{3}{8}$" dia.
taper 1 in 6
$6\frac{1}{2}$"
$10\frac{5}{8}$"
$7\frac{1}{4}$"
5"

When the arms are made of wrought iron the cross-section is circular, one end being made taper to fit a corresponding taper hole in the cast iron boss of the pulley. The other end fits into the rim, which is usually provided with a collar pressing against the rim, as in Fig. 112.

Flange Pulley or Shrouded Rim.

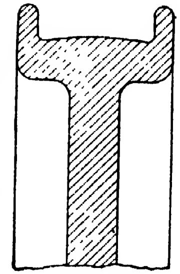
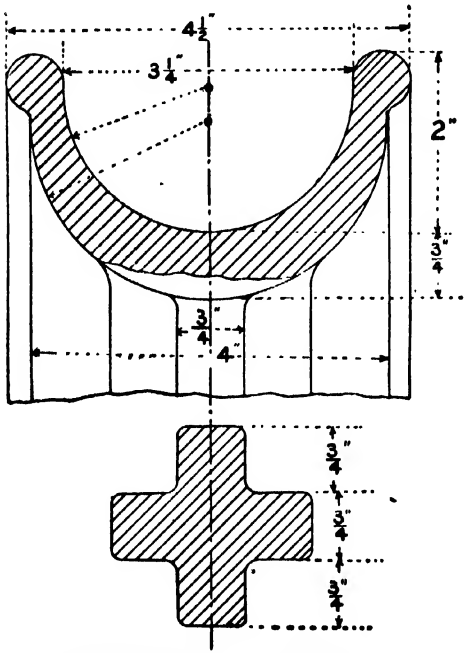


FIG. 113.

By releasing the joint in the rim and also the four bolts at the centre, the pulley can be placed in position on the shaft. The hole is made slightly smaller than the shaft, and the pulley is secured to the shaft by tightening the bolts in the boss.

Example. Draw the wrought iron pulley (Fig. 112). Scale $\frac{1}{3}$. Make any necessary correction in the right-hand view.

Rope Pulley



Cross Section of Arms.

FIG. 114.

Rims of pulleys. The rim of a pulley for a flat belt may be either *flat* or *convex*. The convex rim tends to keep the belt in the middle of the pulley. Two flanges, as in Fig. 113, are sometimes provided for the same purpose. This form of pulley is known as a *flanged pulley*, or *shrouded rim*. Some forms of rims for various pulleys are shown in Figs. 112, 113, 114, 115, and 116.

Rim for rope pulley (Fig. 114). The rope lies in a semicircular groove.

Example. Draw the section of the rim and arm for a rope pulley Fig. 114. Scale half size.

Rim for wire rope. To prevent injury to the rope and to the pulley, the rims of pulleys for wire ropes are made so wide that the rope does not press against the sides of the groove, but is merely in contact on the rounded bottom of the groove. To prevent the rapid wear of the cast iron, the bottom of the groove is lined with wood or, better, with leather. The leather is made in pieces of the shape of the notch and

hammered in When a wood lining is used, the pieces are inserted through an opening in the side of the rim, and when the lining is completed the opening is closed by using a metal plate and set screws. The form of rim is shown in Fig. 115.

Rim for chain pulley. In differential pulley blocks, in cranes, etc., in which chains are used, the rim is of the form shown in Fig. 116.

Use of curved arms. Various practical methods are adopted to ensure uniformity of cooling during the process of casting a pulley. One plan is to uncover the thicker parts of the pulley--such as those at or near the centre—and to leave the thinner portions—such as the rim and arms -covered in the sand.

But even when this precaution is adopted, when the arms of the pulley are straight the unequal cooling, and in consequence unequal contraction, introduces unknown initial stresses in the material and tends to produce fracture--usually at or near the junction of the arm and the rim.

When the arms are curved as in Fig. 117, the initial stresses are lessened owing to the tendency of the arms to straighten during cooling. Three forms of arms are shown in Fig. 117. They are known respectively as a *straight arm*, as a *curved arm*, and as an S-*armed* pulley. The centres for the curves are (as indicated) obtained by using the 30° and 60° set square. This plan gives a mean centre a. As the width of the arm is slightly less near the rim than it is near the centre, two centres must be used; and these may be obtained by setting off half the thickness of the rim on each side of the mean centre.

S-armed pulley. To obtain the mean centres for the curves, make $CD = \frac{2}{3}CB$; through D draw a line at 45° with CB, and Ca perpendicular, thus obtaining the mean centre. Set off, as in the preceding case, distances on each side for the respective centres. The centre for the remaining portions of the curve is obtained at E by drawing BE perpendicular to Da to meet aD produced in E.

Fast and loose pulleys. A common arrangement in a shop or factory is to drive direct from the engine one or more shafts called *main driving* or *line* shafts. These, by means of pulleys and belts, give motion to smaller shafts called *counter shafts* placed in convenient positions at or near the machines to be driven. Any of these machines may require to be stopped at intervals, or restarted without in any manner disturbing the remainder. An arrangement of fast and loose pulleys is used for the purpose. This arrangement consists of two pulleys of equal size, one of which is fastened to the counter shaft by means of

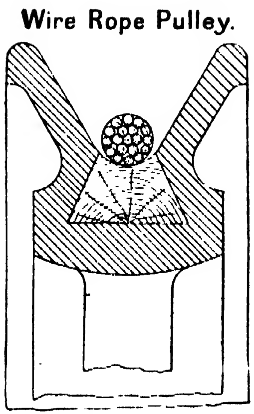


FIG. 115.

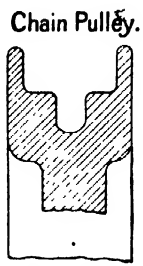


FIG. 116.

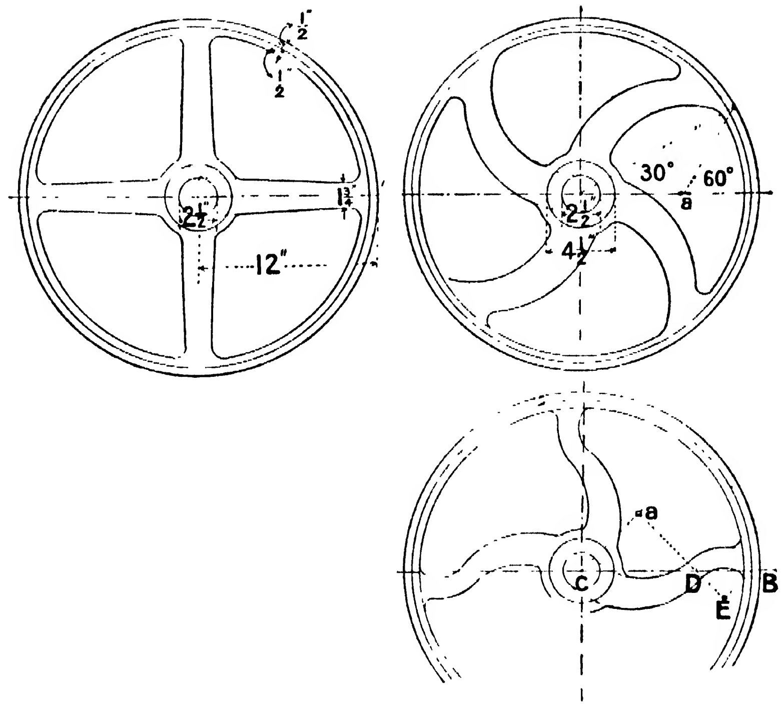


FIG. 117.

a key or a set screw; the other can rotate freely, but any motion in the direction of the length of the shaft is prevented by means of a collar as at **C** (Fig. 118).

Example. Draw $\frac{1}{4}$ size the two views of fast and loose pulleys (Fig. 118).

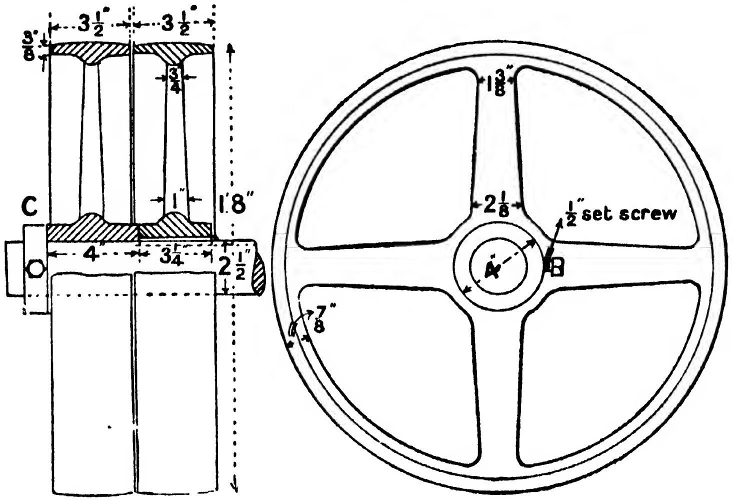


FIG. 118.—Fast and Loose Pulleys.

Speed cones. *Speed cones* are used in machine tools and for many other purposes to drive a machine at different rates of speed. A counter shaft carries—in addition to a fast and loose pulley arrangement—a speed cone (Fig. 119). This cone by means of a belt gives motion to a similar cone placed on the machine and arranged as indicated. The diameter of **A** is 20″ and that of **D** is 10″. The diameters of the two intermediate pulleys may be found by drawing a line from **A** to **D**.

Example. (*a*) Draw the three views of the speed cones, Fig. 119. Scale $\frac{1}{4}$ full size.

(*b*) If the axes of the two shafts are 15 feet apart, find the length of belt required.

(*c*) If the upper speed cone makes 100 revolutions per minute, find the number of revolutions of the lower cone for all positions of the belt.

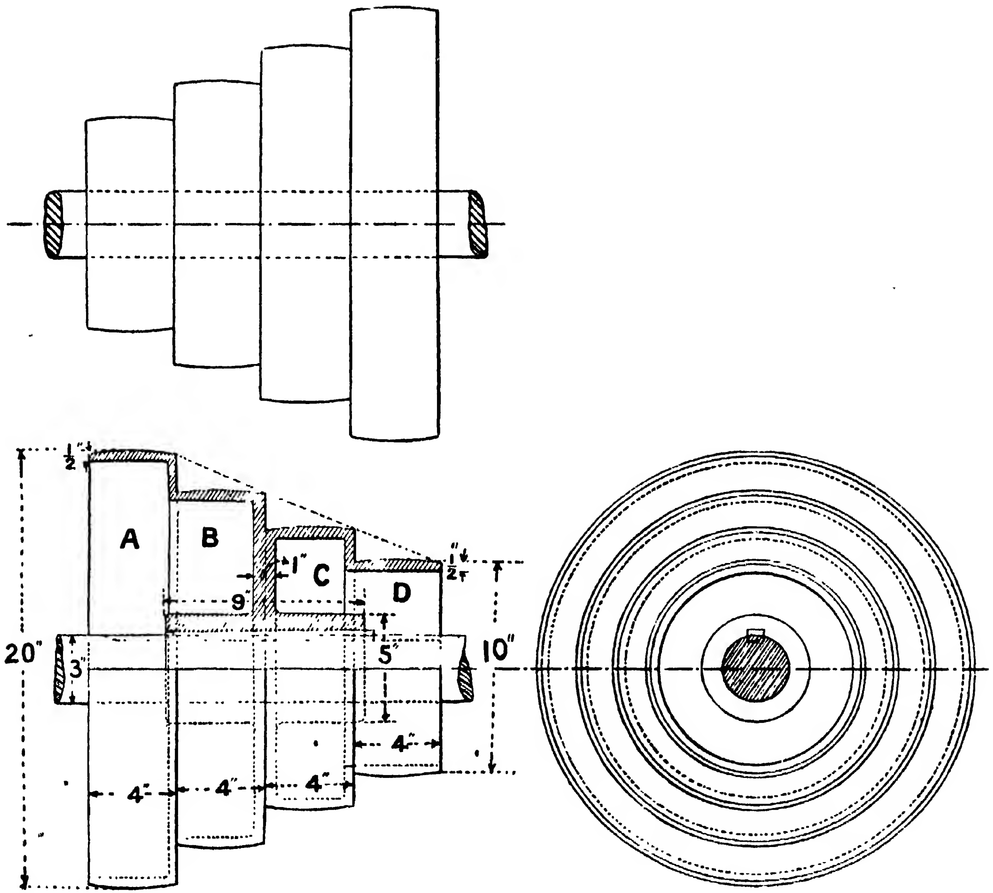


FIG. 119.—Speed Cones.

Example. Draw the sectional elevation, end view, and a plan of the three speed cone (Fig. 120). Scale ½ full size.

Counter shaft. The general arrangement of fast and loose pulleys and speed cones may be seen by reference to Fig. 121. The shaft carrying these is supported by two brackets fastened to pillars, or to

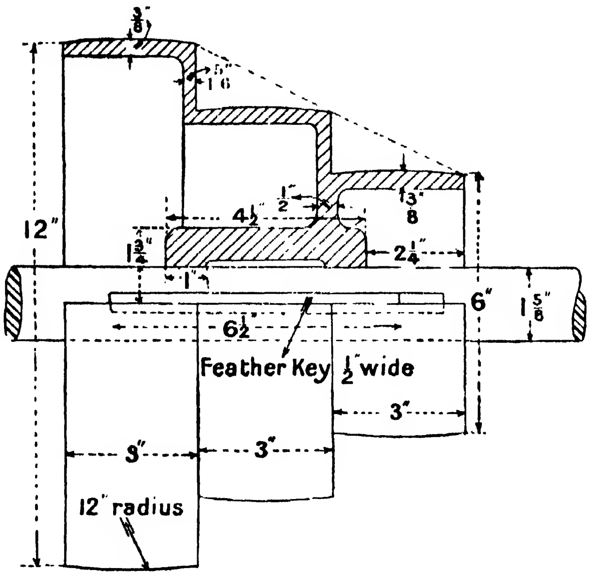


Fig. 120.

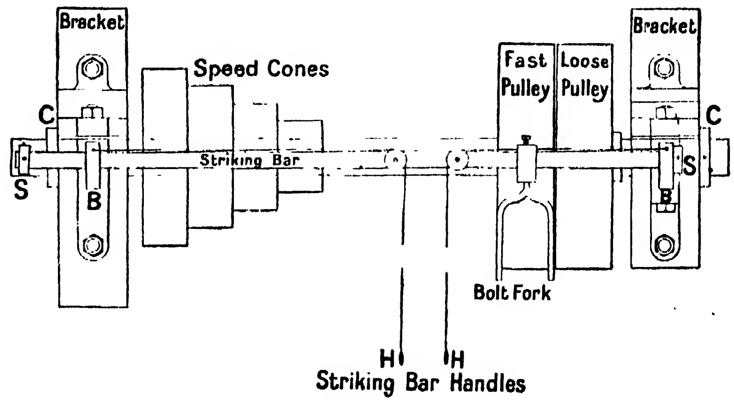


Fig. 121.

any convenient support near the ceiling of the shop. Endlong motion of the shaft is prevented by two collars, **CC**, fixed to the shaft on the outside of each bracket.

The belt is shifted from the fast to the loose pulley, or conversely, by means of a *belt fork.* This fork is fixed to a flat bar, called a *striking bar*, carried by two supports attached to the brackets. The belt fork and striking bar to which it is fastened can be moved to the right or left by means of the

cords and pulleys shown in Fig. 121. Suitable stops, **S**, **S**, prevent the striking bar from being moved too far in either direction.

Rope pulleys. Flat belts are not suitable for the main driving pulleys in large engineering or other works on account of the tendency to slip, and also the liability to total stoppage in the case of a breakdown. Spur gearing may be used, but rope driving offers many advantages over either belts or spur gearing.

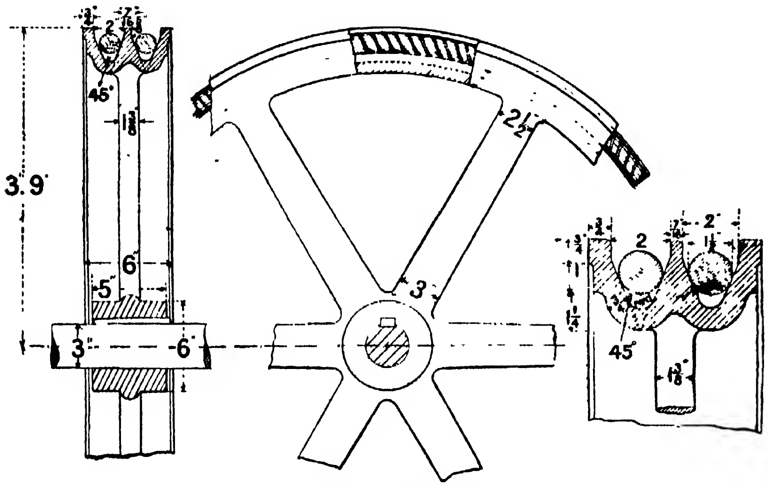


FIG. 122.—Rope Pulley.

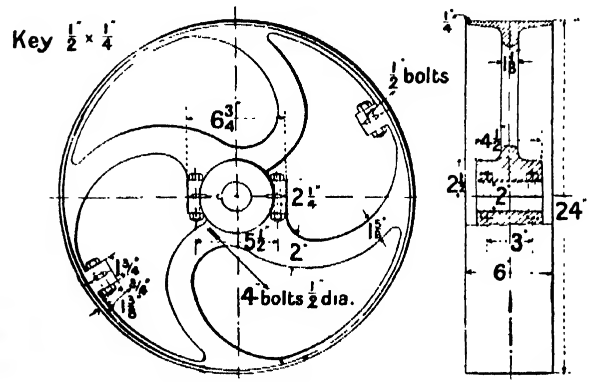


FIG. 123.—Curved Armed Pulley.

Formerly the ropes used were made from Manilla or Russian hemp, but *cotton* is used now invariably. The ropes vary in diameter from $\frac{3}{4}''$ to $2''$. The pulleys are usually of cast iron, and the rims grooved to suit the ropes.

One form of the rim is shown in Fig. 122. It will be noticed that the rope rests on the sides of the groove and not on the bottom. The diameter of the pulley used is generally not less than 30 times the diameter of the rope, and the horizontal distance between the pulleys not less than 20 feet, but may be 100 feet. The driving side of the rope should be on the lower part of the pulleys and the slack side above.

The speed of the rope varies considerably. Speeds of 2000 ft. per minute are sometimes used, but the usual speed is about 4000 ft. per minute. The number of grooves in the rim depends upon the power to be transmitted. When this power is considerable, the number may be 60 in the case of engines developing upwards of 4000 H.P.

The width of the pulley face can be found by multiplying the number of grooves by the pitch and adding to the product the thickness of the outer flanges.

Example. Draw, to a scale of $\frac{1}{4}$ full size, a sectional elevation and end view of the rope pulley (Fig. 122). Diameter of pulley, 3 ft. 9 in.

Example. Draw half size the two views of a curved arm split pulley (Fig. 123).

EXERCISES. V.

1. Give any reasons you can why the rims and arms of cast iron pulleys are often curved. What are the objections to straight armed pulleys and how are these overcome?

2. Show, by sketches, an arrangement of fast and loose pulleys. In what circumstances would such an arrangement be used?

3. Show the cross sections of two forms of arms used for cast iron pulleys.

4. Show, by sketches, the construction of a speed or stepped cone pulley, giving an example where such a pulley is used.

5. Sketch and describe three distinct ways by which a flat belt may be retained on the surface of a pulley when running. [B.E.]

6. Show, by sketches, the construction of a belt-pulley having a light malleable metal rim, and made in such a way that it may be fixed to the shaft without threading it over the end. [B.E.]

7. With the aid of a graphical construction determine the length of a crossed belt required to embrace either of two pairs of pulleys which are mounted on parallel shafts 3′ 6″ apart. The smaller pulley on each shaft is 8″ diameter and the velocity ratio at the higher speed is to be four times that at the lower speed.

8. A shaft running at 100 revolutions per minute drives another by a leather belt. The pulley on first shaft is 18″ diameter; the pulley on the second shaft is 30″ diameter. Sketch the arrangement and find the speed of the second shaft. If the same belt is to drive the second shaft at 40 revolutions per minute, find the diameters of the two pulleys.

9. Sketch in section the rims of pulleys suitable for (1) leather belting, (2) cotton rope gearing, (3) wire rope.

10. Show, by sketches, the construction of a split pulley for a line of shafting, explaining how the pulley is secured to the shaft.

11. The section of the rim of a pulley, 24 in. diameter, is given (Fig. 114). The boss is 6 in. diameter and $5\frac{1}{2}$ in. long bored out to 3 in. diameter. It has six arms of the cross section shown. Draw complete section and elevation. Scale $\frac{1}{4}$.

12. A pulley, 5 ft. diameter, rotating at 120 revolutions per minute, is connected by a belt to a pulley, 2 ft. diameter, on a main shaft. On the main shaft a pulley, 3 ft. diameter, transmits motion by means of a belt to one of 1 ft. 9 in. diameter on a counter-shaft. On the counter-shaft are speed cones, the largest and smallest diameters being respectively 12 in. and 6 in.; these drive a corresponding set of speed cones on the spindle of a lathe. Find the highest and lowest speeds at which the lathe can rotate. Sketch the arrangement.

13. A fly-wheel, 6 ft. diameter, revolves 150 times per minute; find the speed of the rim in feet per second. A belt connects the fly-wheel to a pulley, 2 ft. 6 in. diameter, on another shaft. If the slip of the belt is 2 per cent., find the speed of the driven shaft.

14. The speeds of a driving pulley and the follower are 140 and 80 revolutions per minute respectively, and the sum of their diameters is 66 in. Find the diameters of the driver and follower.

CHAPTER VI.

WHEELS.

Linear and angular velocity. If two cylinders, **A** and **B** (Fig. 124), the axes of which are parallel, are pressed tightly in contact, then when one rotates the adhesion of the surfaces will cause rotation of the other. If no slipping occurs, the surface of one will move at the same speed as that of the other. This

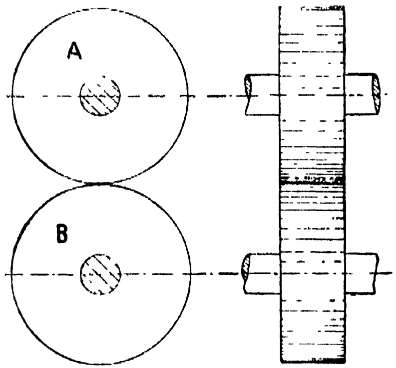


FIG. 124.

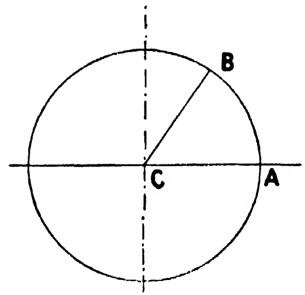


FIG. 125.

surface speed is called *linear velocity*, and is usually estimated by the number of feet moved through in a unit of time by a point in the rim.

Angular velocity. Another method of estimating the speed is by *angular velocity*. Thus, in one rotation, the angle moved through by any radius, such as **CB**, would be 360° or 2π radians. A *radian*

indicates an angle such that the length of the arc **AB** (Fig. 125) is equal to the radius **AC**. That is to say the angle **ACB** is $180° \div \pi$ or $57°\cdot3$.

The relation between linear and angular velocity is given by

$$\mathbf{v} = \omega \mathbf{r} \qquad (1)$$

where **v** is the velocity of **B** in feet per second, **r** the distance in feet of **B** from the centre **C**, and ω denotes the angular velocity in radians per second.

If the two cylinders are of equal size, they will each make the same number of turns in the unit of time. If one cylinder is twice as large as the other, the smaller cylinder will make two revolutions whilst the larger makes one. If one cylinder is three times the size of the other, then one will make three revolutions whilst the other makes one, and so on. These facts may be expressed readily by using symbols. If **n** revolutions are made in unit time, then $\omega = 2\pi\mathbf{n}$.

Also, from (1), $\mathbf{v} = 2\pi\mathbf{nr}$. Thus, $\mathbf{n} = \dfrac{\mathbf{v}}{2\pi\mathbf{r}}$.

From this result it is seen easily that for the same surface speed, as **r** increases **n** diminishes. Thus if **r** is doubled, **n** is one-half its previous value.

Example. A cylinder 6 ft. diameter makes 30 revolutions per second. What is its angular velocity? Also what is the linear speed of a point in its rim?

Here $\omega = 2\pi\mathbf{n} = 60\pi$ radians

$\mathbf{v} = \omega\mathbf{r} = 360\pi$ ft. per sec.

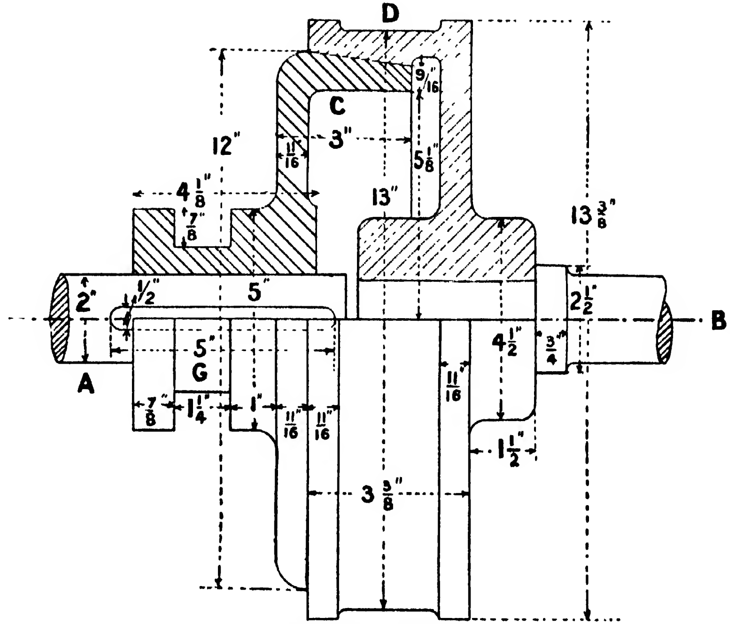


FIG. 126.—Friction Clutch.

Friction clutches. The arrangement illustrated in Fig. 124 is used in modified forms in so-called *friction grips* or *clutches*, one of which is shown in Fig. 126. **A** is the driving shaft on which a friction clutch is mounted, rotating with the shaft but by means of a

suitable lever operating in the groove **G**, the clutch can be moved backwards or forwards along the shaft. When in this manner the two inclined surfaces of **C** and **D** are pressed tightly together, rotation of **A** will ensure rotation of **B**, and **B** will remain at rest when the clutch **C** is not in contact.

Example. Draw the sectional elevation of the friction clutch shown in Fig. 126. Draw also a plan and an end view. Scale half size.

Teeth of wheels. The method shown in Fig. 124, although useful for many purposes, such as friction wheels, etc., is not always suitable for the transmission of force, for even when the two surfaces are pressed together resistances to motion may produce slipping. In order to prevent slipping, projections called *teeth* are provided on each cylinder, and by this means the rotation of one shaft can be transmitted with accuracy to the other, the motion being the same as if two cylinders were in contact. These cylindrical surfaces are called *pitch surfaces*, and the two circles representing the circumferences of the cylinders are the *pitch circles* of the wheels. Such circles are always assumed to exist in every pair of wheels in gear, and it is important in wheels gearing together so to shape the teeth that the pitch circles will just touch each other without any slipping.

The length of the line or arc joining the centres of two consecutive teeth, as **AC** (Fig. 128), is called the *pitch of the teeth*, or simply the *pitch*. The various parts of the tooth of a wheel are expressed in terms of the pitch. The distance the tooth projects above the pitch circle is called the *face*, the distance below the *flank*. The thickness of the tooth, which is measured on the pitch circle, may be denoted by **T**, the width of the space by **S**, and the thickness of the rim by **R** (Fig. 127). All these quantities are expressed in terms of the pitch, and therefore are found easily when the pitch **p** is known. The following proportions represent fairly average values:

H = height of tooth above pitch circle	= 0·3	**p.**
D = depth ,, below ,,	= 0·4	**p.**
T = thickness of tooth	= 0·48	**p.**
S = width of space	= 0·52	**p.**
R = thickness of rim	= 0·48	**p.**

Other proportional numbers are given in Fig. 128.

Proportions not quite so exact as the preceding are as follows: Divide the pitch into 15 parts (Fig. 127), and take 8 for the width of space **S**, 7 for **T**; also make **H** = 5 and **D** = 6 of the parts respectively.

That is, $S = \frac{8}{15}p, \quad T = \frac{7}{15}p, \quad H = \frac{5}{15}p, \quad D = \frac{6}{15}p.$

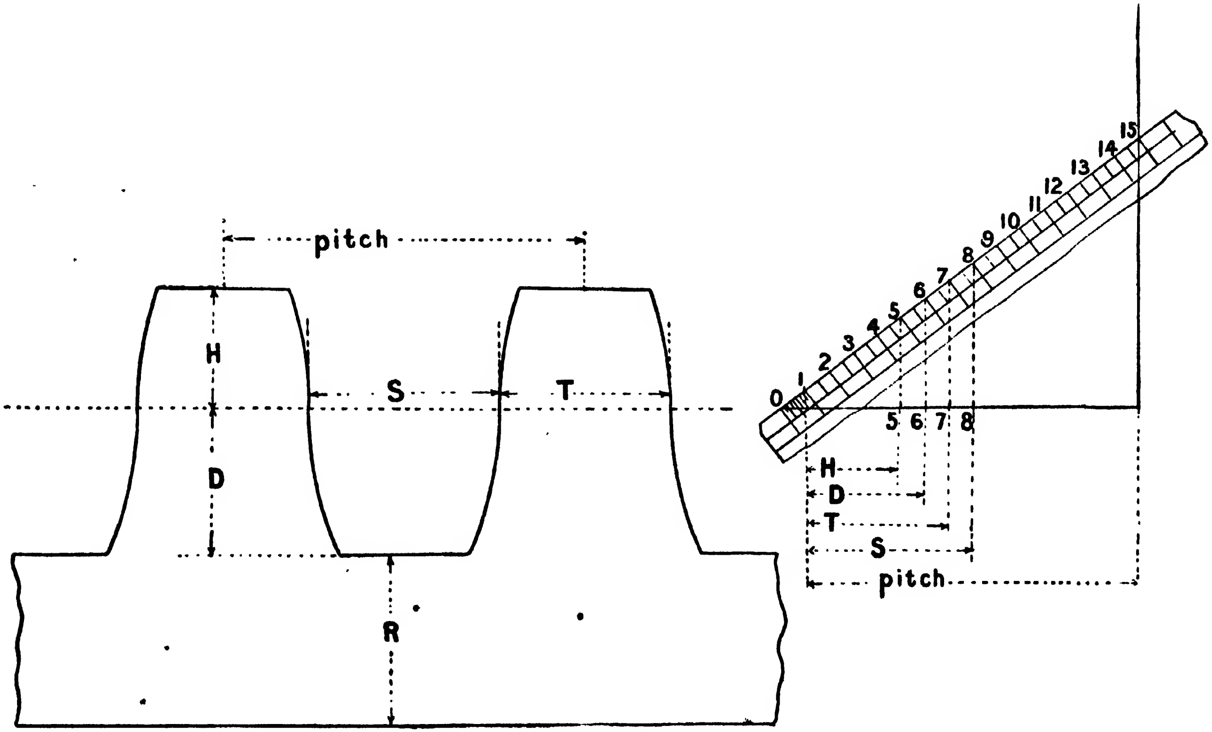


FIG. 127.

When the teeth are made accurately, as in machine moulded wheels and also in machine cut teeth, the above proportions may be modified, *i.e.* the thickness **T** may be increased slightly and the width of space **S** diminished slightly.

For more detailed information reference should be made to works dealing with the subject.

The beginner should notice carefully that the fractional parts of the pitch denoted by **T** and **S** are, when added together, equal to **p**.

The proportions which may be adopted for the arms of a wheel can also be expressed in terms of **p**, as in Fig. 128.

It will be found to be a good plan to make drawings of wheel teeth on cardboard or sheet zinc, and afterwards to cut these out as carefully as possible. Then, by placing them in gear, the student is enabled to test the accuracy of his work.

It will be obvious from the preceding definition of *pitch* that the number of teeth in a wheel multiplied by the pitch will give the circumference of the pitch circle. But this circumference is also the diameter of the pitch circle multiplied by π. Hence, we have the relation,

$$\text{Diameter of pitch circle} \times \pi = \text{Number of teeth} \times \text{pitch},$$

$$\pi \mathbf{d} = \mathbf{np}.$$

where **d** denotes diameter, **n** the number of teeth, and **p** the pitch.

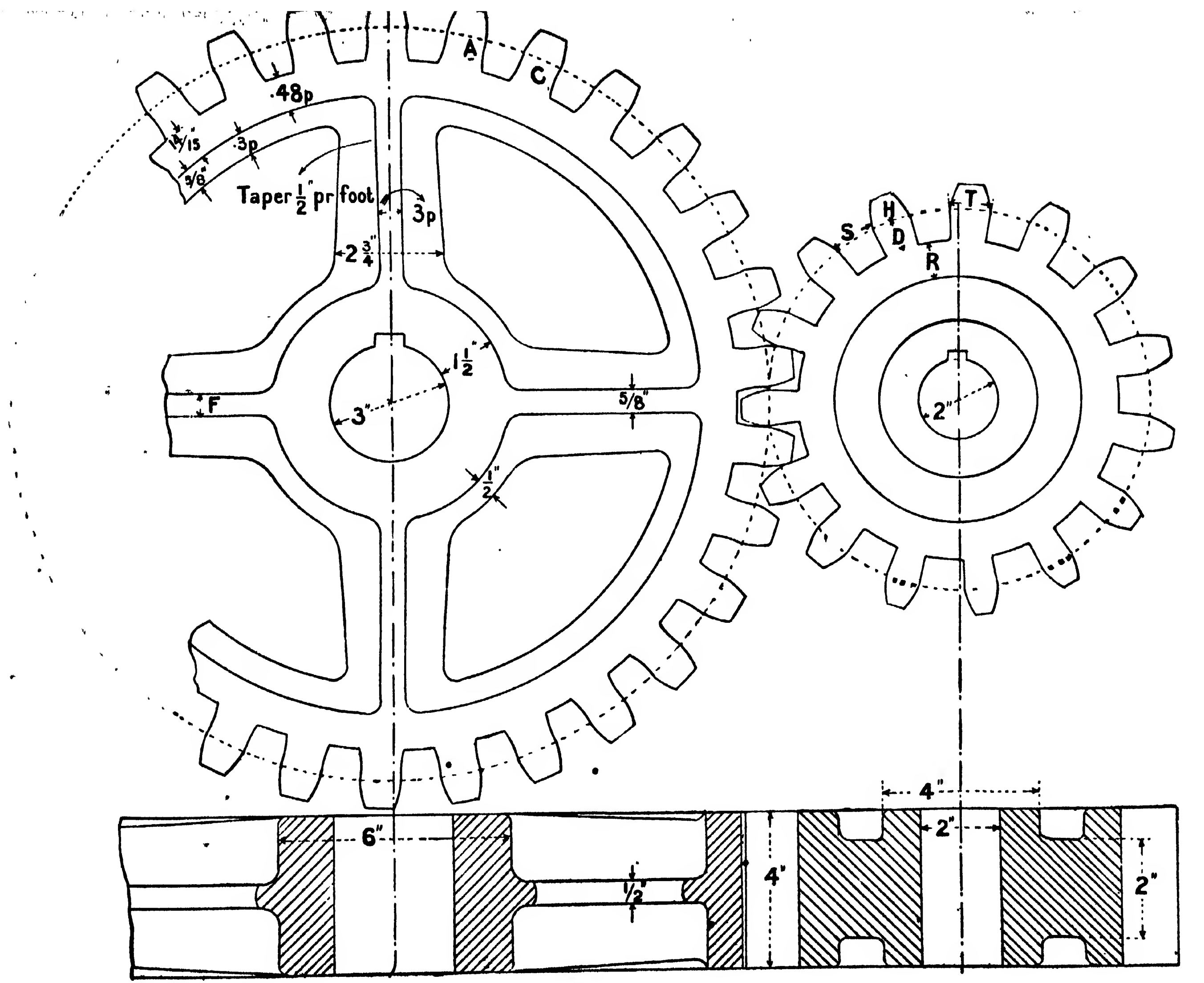
From this relation, when any two of the three terms **n**, **p**, and **d** are given, the remaining term may be obtained. The value of π is usually taken to be $\frac{22}{7}$ or 3·1416. The former value is in many cases sufficiently accurate, and the latter when expressed in the form 3·142 is very convenient for use with four-figure logarithms.

Example 1. A wheel has 30 teeth of 2″ pitch. Find the diameter of the pitch circle.

$$\mathbf{d} = \frac{30 \times 2}{\pi}$$

$$\log \mathbf{d} = \log 60 - \log \pi = 1{\cdot}2810\,;$$

$$\therefore\ \mathbf{d} = 19{\cdot}1 \text{ inches}$$


A
C
.48p
1/15
.3p
5/8"
Taper 1/2" pr foot
3p
2 3/4"
1 1/2"
F
3"
5/8"
1/2"
T
H
S
D
R
2"
4"
6"
2"
1/2"
4"
2"

Example 2. The pitch of the teeth of a wheel is to be 3″ and the diameter of its pitch circle as nearly as possible equal to 4 ft. Find the number of teeth.

$$n = \frac{48 \times \pi}{3} = 16\pi,$$

$$\log n = \log 16 + \log \pi = 1{\cdot}7013\,;$$

$$\therefore\ n = 50{\cdot}27.$$

It is obvious that there cannot be a fractional part of a tooth in a wheel. Hence we may take 50 as the nearest whole number for the number of teeth, and calculate the diameter thus:

$$d = \frac{50 \times 3}{\pi} = \frac{150}{\pi},$$

$$\log d = \log 150 - \log \pi = 1{\cdot}6789\,;$$

$$\therefore\ d = 47''{\cdot}74.$$

Rack. The circumference of a circle approaches nearer and nearer to a straight line as the radius of the circle is increased. When the radius is considered to be infinitely long, the pitch circle becomes a straight line, the proportions adopted for the teeth obviously remain unaltered.

Wheels and pinions. When two wheels of unequal size are in gear, the larger is usually known as a *wheel* and the smaller as a *pinion*.

In Fig. 128 the elevation and section of a **spur wheel and pinion in gear** is shown. The wheel has 30 teeth of 2″ pitch and the pinion 15 teeth of 2″ pitch.

The diameter of the pitch circle of the wheel is given by $d = \frac{30 \times 2}{\pi} = 19''{\cdot}1$.

The diameter of the pitch circle of the pinion $= \frac{19{\cdot}1}{2} = 9''{\cdot}55$.

Draw a circle 19″·1 diameter and divide the circumference into 30 equal parts. To obtain the proportions for the teeth, draw a line **AB** equal to the pitch and divide this, as in Fig. 127, into 15 equal parts. Make the thickness of the tooth 7 of these parts, width of the space 8, the distance **H** = 5 and **D** = 6 parts.

The curves for the teeth are usually drawn with centres on the pitch circle and a radius equal to the pitch. The flanks of the pinion may be made radial, *i.e.* drawn to the centre of the pitch circle.

Example. Draw the given wheel and pinion (Fig. 128). Scale half full size.

Forms of the teeth. It is beyond the scope of a book of this kind to enter fully into the shapes which are adopted for the curved portions of the teeth of wheels. The form adopted may be that of a *cycloid.* Such a curve is formed by a point in the periphery of a cylinder or disc rolling on a horizontal surface; it is called an *epicycloid* when the disc referred to rolls on the *outside* of a fixed circle and a *hypocycloid* when it rolls on the *inside.* The disc is usually called the *rolling circle.*

It is instructive to obtain these curves not only by the usual geometrical methods but also experimentally. Thus, a sector of a circle representing a portion of the pitch circle may be made from a piece of thin wood, sheet zinc, etc., and the rolling circles may consist of small discs of wood or other material.

A convenient method is as follows: Draw the circle representing the pitch circle of a wheel; draw on a piece of tracing paper a smaller or rolling circle; make a mark on the circumference of the pitch circle and a corresponding mark on the tracing paper; put the two circles touching each other with the marks coincident; then, inserting a pricker, or the needle point of a pair of dividers, roll the smaller circle on the larger one, marking successive positions of the point. In this manner the two curves forming the upper part or *face*, and the lower part or *flank* of a tooth may be obtained.[1]

Rolling circle. The diameter of the rolling circle is usually made equal to *twice the pitch.* An exception to this rule is furnished by a set of change wheels for a lathe, in which the flanks of the smallest wheel in the set are made *radial*, *i.e.* the diameter of the rolling circle is made equal to the radius of the pitch circle of the smallest wheel of the set.

Conventional methods. In working drawings it is customary to draw the pitch circle, or pitch circles, and to write on the drawing the necessary particulars, such as number of teeth, pitch, etc. Or two or more teeth and the arms, boss and shaft may be shown.

Spur and bevel wheels. When the axes of two shafts are parallel and a suitable distance apart, they may be connected by *spur wheels.* When the axes meet at an angle, *bevel wheels* are used. The pitch surfaces in the first case are cylinders, those of the latter are *cones* and are called *pitch cones* (Fig. 129).

[1] The curve traced out by the end of a piece of flexible string unwound from a circle and kept tight, is called an *involute*, and is usually better adapted than curves of a cycloidal form.

In drawing bevel wheels, a conventional method frequently adopted is to draw—as in Fig. 129—

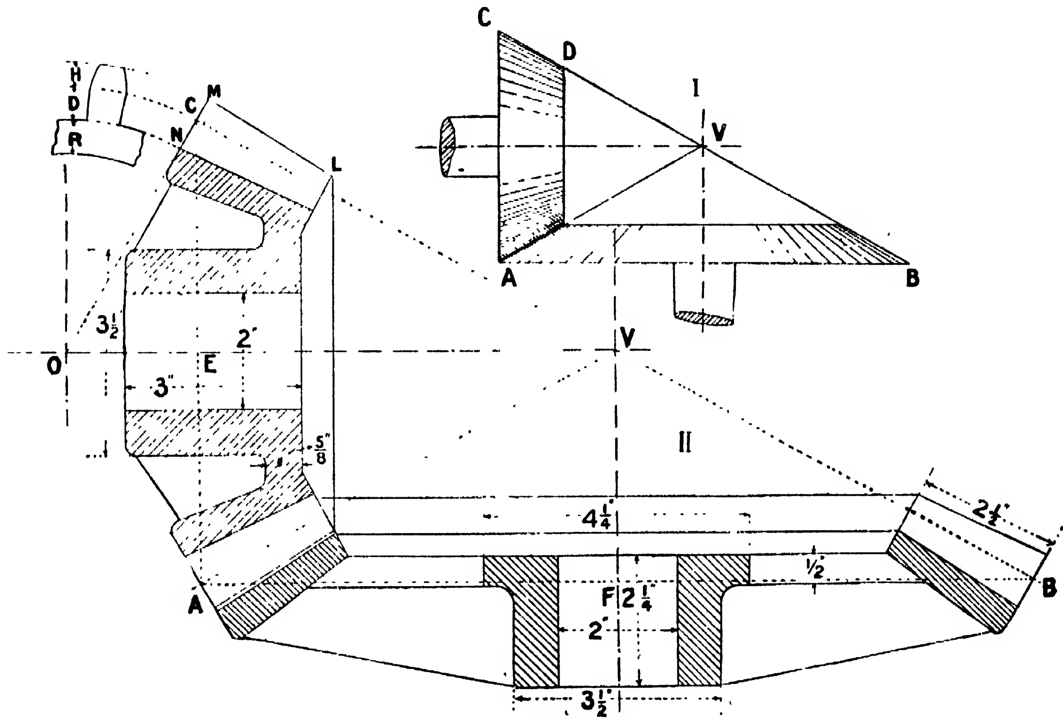


FIG. 129.—Bevel Wheels.

portions of the two pitch cones and to write on the drawing the number of teeth, pitch, and any other necessary information.

Another method is to draw the wheels in section; only two teeth, drawn in elevation, are shown and any necessary data not indicated by the drawing may be written on it.

Mitre wheels. When the two bevel wheels which gear together are of equal size, they are called *mitre wheels*, and the *pitch cones* of the wheels can be shown when the diameters of the pitch circles of the wheels are known. In this instance, as in the case of two wheels of unequal size, the diameter of the pitch circle of either wheel can be obtained when the number of teeth and the pitch of the teeth are given. The simple necessary calculation may be seen from the following case of two unequal wheels.

Example. (*a*) Draw the projection of two bevel wheels having 20 and 36 teeth respectively. $1\frac{1}{4}''$ pitch. (*b*) Draw a sectional elevation and end view of the smaller wheel and show the development of one tooth. Width of face $2\frac{1}{2}''$.

From the relation $\pi \times \text{diameter} = \text{No. of teeth} \times \text{pitch}$

we have,
$$\text{diameter of large wheel} = \frac{36 \times 1\frac{1}{4}}{\pi} = 14''\cdot32,$$

$$\text{diameter of smaller wheel} = \frac{20 \times 1\frac{1}{4}}{\pi} = 7''\cdot96.$$

(*a*) These wheels would in many cases be shown in a conventional manner, as in Fig. 129. (I). Two lines, **AB** and **AC**, are drawn at right angles to each other; **AC** is made equal to $7''\cdot96$, the diameter of the smaller; and **AB** equal to $14\cdot32''$, the diameter of the larger wheel. The centre lines meeting at **V** are next drawn. Join **C**, **A**, and **B** to **V**; then **VCA**, and **VAB** will represent the pitch cones of the two wheels. Mark off **CD** equal to the width of face, and the conventional drawing may be completed as shown. In addition, lines roughly indicating the teeth may be drawn, as shown.

(*b*) The two wheels may be shown in section as in Fig. 129. To draw the development of one tooth we may proceed as follows:

Obtain **V** the common vertex of the two cones, as in the preceding drawing, and join **C**, **A**, and **B** to **V**. Draw a line **CO** at right angles to **CV** and meeting **VE** produced in **O**. With **O** as centre and **CO** as radius, describe an arc of a circle denoting the pitch circle of the pinion. Set up the height **H** and depth **D** of the tooth. With **O** as centre obtain the points **M** and **N**; draw a line from **M** to centre **V**, and cut off a distance **ML** = width of face = $2\frac{1}{2}''$. Complete the sections of the wheel and pinion using the dimensions given. Scale full size.

Skew bevel wheels. It will be obvious that when the axes of the two shafts, as in Fig. 129, meet at a point, one shaft may be of any desired length in either direction, but the other must terminate before it reaches the common centre V.

In many cases, to provide suitable bearing surfaces and for other purposes, it is necessary that both shafts shall be made to pass each other, and what are called *skew bevels* are used, in which the centre line, or axis of each shaft, does not when produced pass through a point V but on one side of it.

Familiar examples of wheels of this kind are to be found in "Engineers' drills," etc.

Arms of wheels. The shape adopted for the arms of a wheel depends chiefly upon its size. For small

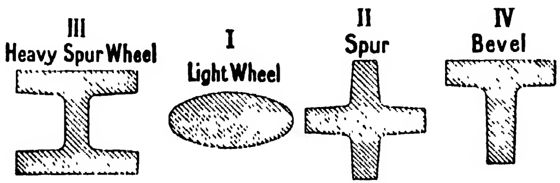


FIG. 130.—Sections of Arms of Wheels.

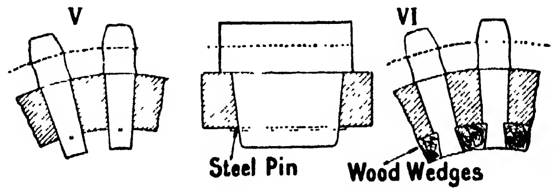


FIG. 131.—Rims of Mortise Wheels.

wheels, the cross section may be an ellipse, or a cross, as at **I** and **II** (Fig. 130). For large and heavy wheels, a double tee shape as at **III**, and for bevel wheels, a tee form shown at **IV** may be used.

Mortise wheels. The noise and vibration caused by two wheels in gear, when rotating rapidly, is considerably diminished when one of the wheels is provided with wooden teeth, and the wheel is then known as a *mortise wheel*. In addition, the wear chiefly occurs on the wooden teeth and the teeth can be replaced readily when worn. Such a wheel, usually made of cast iron, is cast with a series of rectangular holes in the rim; into each of these openings wooden blocks are fitted tightly, and in addition usually fastened by means of pins passing through each tooth on the under side of the rim (as at V, Fig. 131), or wooden wedges (as at VI, Fig. 131) are inserted for the same purpose. The form of rim for a mortise bevel wheel is shown at VII, Fig. 132.

When the wooden blocks are fitted to the rim, the wheel is put into the lathe and the blocks machined on the face and edges. Finally the blocks are cut to the required shape either by hand or machinery.

Shrouded wheels. In small wheels, such as in the pinions, used in cranes, etc., the width of the rim is frequently made wider than the teeth and of a size to reach to the full height or half the height

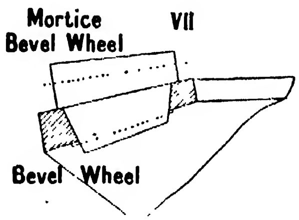


Fig. 132.

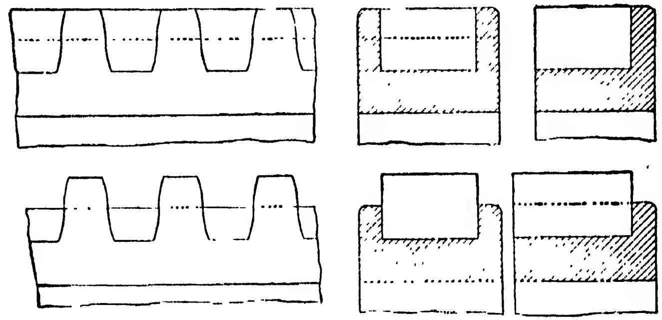


Fig. 133. Shrouding.

of the tooth on one or both sides of a tooth (Fig. 133). This plan is called *shrouding*, the object being to strengthen the teeth.

EXERCISES. VI.

1. What is the meaning of the terms pitch, breadth of face, thickness of tooth, pitch circle, pitch line, rim, arm, and boss as applied in toothed gearing?

2. A spur wheel has teeth of 3 inches pitch. Sketch a tooth and mark on it the thickness at the pitch line, and the height above and depth below the pitch line. What names are given to these distances?

3. Show by a sketch what is meant by the clearance of wheel teeth.

4. Give sketches of a mortise open wheel showing the form of the rim and of the teeth, and the method of fixing the latter. In what circumstances would mortise wheels be used?

5. Two shafts intersect at right angles and are connected by bevel wheels with 22 and 44 teeth

respectively of 1″ pitch. Draw the pitch surfaces of the wheels, and find the development of the conical surfaces on which the shapes of the ends of the teeth are set out.

6. Sketch in section a pair of bevel wheels in gear with one another. The centre lines of the shafts and the pitch surfaces are to be shown.

7. Two bevel wheels connecting shafts at right angles have respectively 12 and 30 teeth, the pitch being 2″. The width of face is 4″. Set out the pitch surfaces of the wheels. Show also the development of one tooth of the smaller wheel, the flanks being radial and the diameter of the rolling circle for the face equal to twice the pitch. [B.E.]

8. Draw to scale, full size, one tooth of a pinion which has 12 teeth of $2\frac{1}{4}''$ pitch, the rolling or describing circle for the teeth being 4·3 times the diameter.

9. A spur wheel has a pitch circle 30 inches diameter with pitch of teeth 2 inches. Sketch a suitable tooth for this, and insert all the necessary dimensions.

10. Make a sketch of 4 teeth for a rack, 3″ pitch. Write on your sketch the various dimensions.

11. Write down ordinary proportions, in terms of the pitch, for the teeth of wheels. Set out to scale the correct form of a tooth for a spur pinion of 10 teeth 2″ pitch, the rolling circle being such as to give radial flanks.

12. Set out to scale a cycloid, the diameter of the rolling circle being 2″. Draw one tooth of a rack, 1″ pitch, the faces and flanks of the teeth being portions of the above cycloid.

13. Draw full size two views of one tooth of a mitre wheel of 16 teeth, $1\frac{1}{2}''$ pitch, $2\frac{1}{2}''$ broad, the size of the rolling circle being such that the teeth have radial flanks.

14. Describe how the parts of a large spur wheel are put together, and explain why the wheel is made in segments.

15. Describe the construction of a mortise spur wheel. (*a*) In what circumstances can such a wheel be used with advantage? (*b*) What kind of wood is used for the teeth? (*c*) Describe the process of recogging such a wheel.

16. A pinion of 12 teeth, 2″ pitch, gears with a rack. Draw, full size, one tooth of the pinion and the rack, the rolling circle to be such as to give radial flanks to the teeth of the pinion.

17. Sketch and describe the construction of a gearing chain and toothed pulley. Give two examples c such a gear, pointing out the special advantages leading to its adoption.

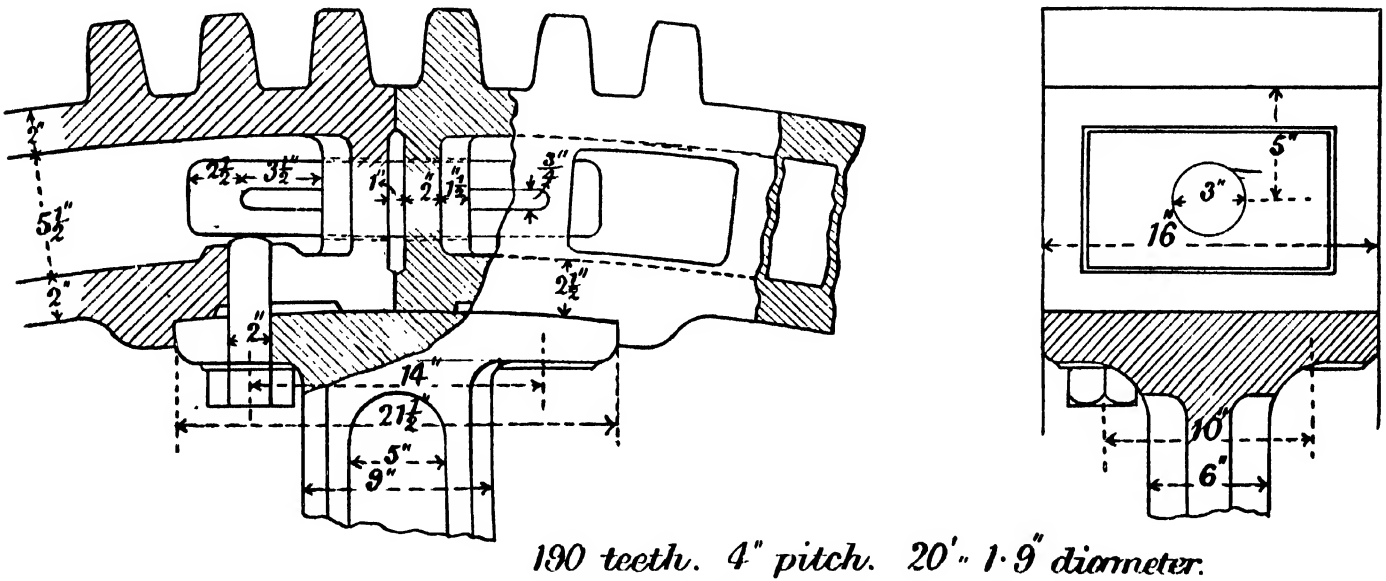


FIG. 134.

18. A segment of a large spur wheel is shown in Fig. 134, the portion shown may be drawn straigh instead of curved. Scale $\frac{1}{4}$. [B.E.]

CHAPTER VII.

BEARINGS.

Bearings. All rotating shafts and bearings require to be supported at various places along their lengths. These supports or *bearings*, in the case of a spindle or shaft which rotates slowly or intermittently,

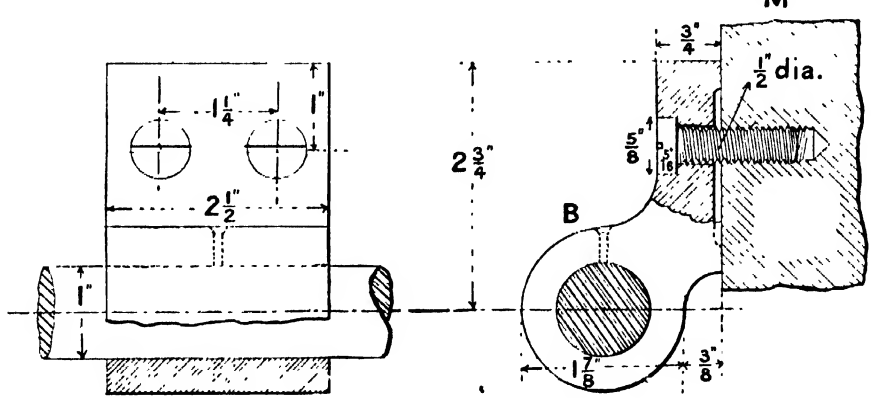


Fig. 135.—Small Bracket.

may be of simple form. A simple form of bearing may consist of some kind of cast-iron bracket in which a hole is bored to fit the shaft. Such brackets are made in a variety of forms depending upon the purpose for which they are intended. A simple bracket, **B**, which may be fastened to one side of a machine, **M**, by

means of the tap bolts indicated, is shown in Fig. 135. The hole is bored to fit the shaft, and there is no adjustment for wear.

Example. Draw the two views of a simple bracket (Fig. 135). Scale full size.

Another form of bracket is shown in Fig. 136. In this case, the hole in the bracket is made larger than the shaft, and the space between the bracket and the shaft is filled by a brass cylinder. The outside of the brass bush is made to fit the hole in the bracket tightly, and the inside is bored to fit the shaft. A small screw, having one half its diameter in the bracket and the other half in the bush, is usually inserted to prevent rotation of the bush.

In this arrangement not only is the friction between the shaft and its bearing reduced by the use of the softer metal, but, in addition, the bush, when worn, can be readily replaced.

Example. Draw the two views of the bracket (Fig. 136). Scale full size. Also draw an end view.

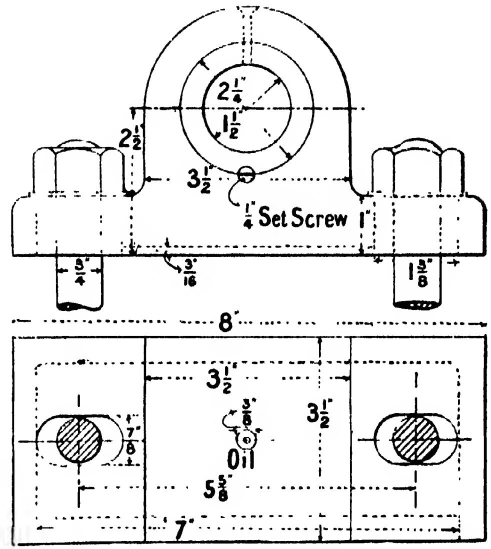


FIG. 136.—Bracket.

Pedestal. When a brass bush, as in Fig. 137, is made in two parts and means provided so that, as wear takes place, the two parts can be drawn closer together, we obtain an arrangement in which compensation for wear can be made. The *pedestal*, or *plummer block*, one form of which is shown in Fig. 137, consists of a cast-iron block, **B**, and a cast-iron cap, **C**, made to fit the block. Two brass steps, **S**, are fitted to the block, the parts on the steps marked **a**, **a**, fit the corresponding parts on the block, and the halves of the steps can be drawn together by means of two bolts, one of which is shown at **b**. These bolts pass through two holes in the pedestal and cap as shown.

The holes both in the block and the cap are somewhat larger than the diameter of the bolt as shown in Fig. 137. This allows for slight irregularities in the casting. In a similar manner, the square head of the bolt fits somewhat loosely a corresponding hole in the block.

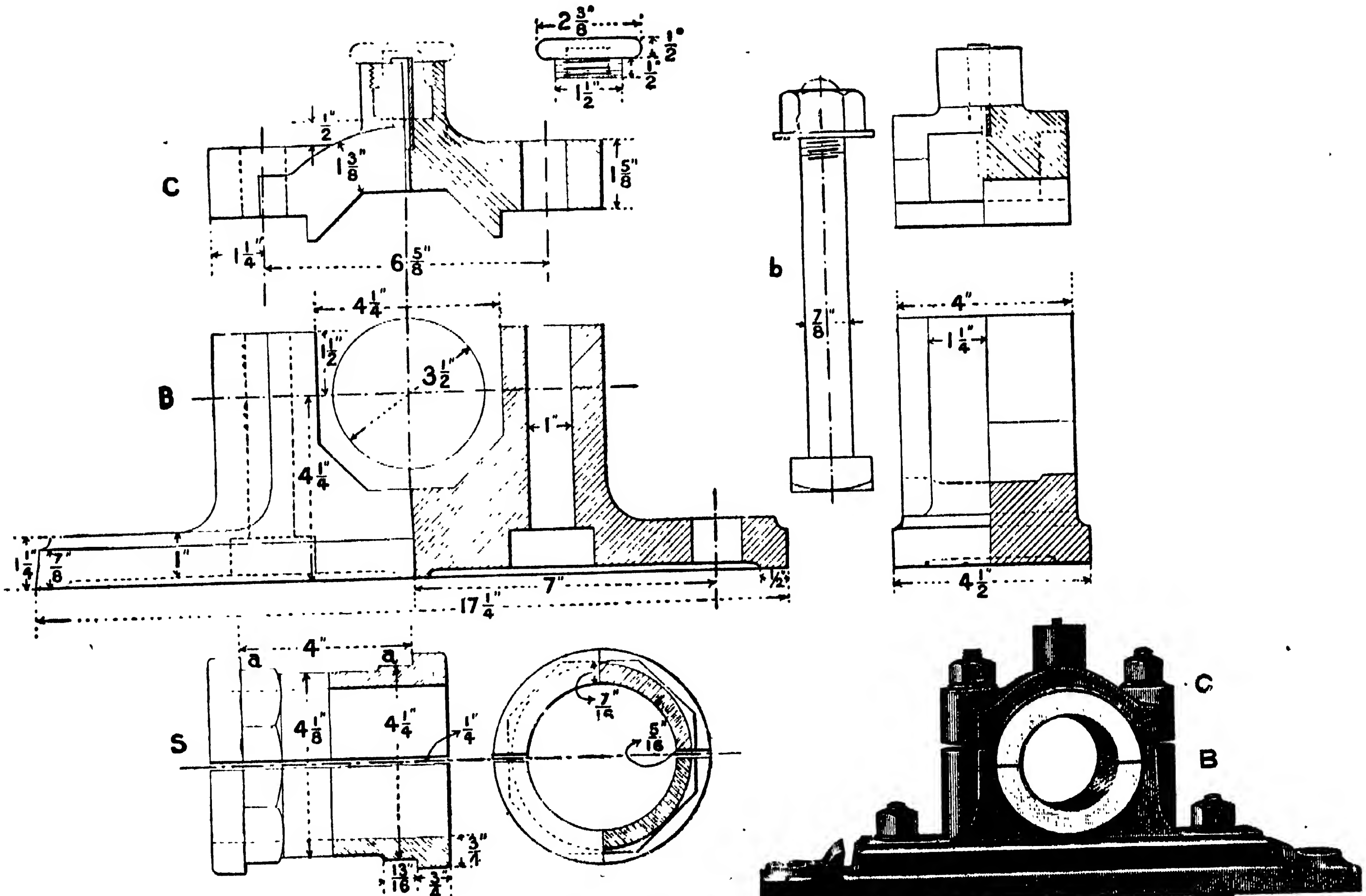


FIG. 137.—Details of Pedestal.

Example. Draw the details of the pedestal (Fig. 137). Also draw a sectional elevation, end view and plan, with all the details inserted in place in the pedestal and showing the pedestal on the wall plate (Fig. 138). Bolts, $\frac{7}{8}''$ diameter. Scale, 6" – 1'.

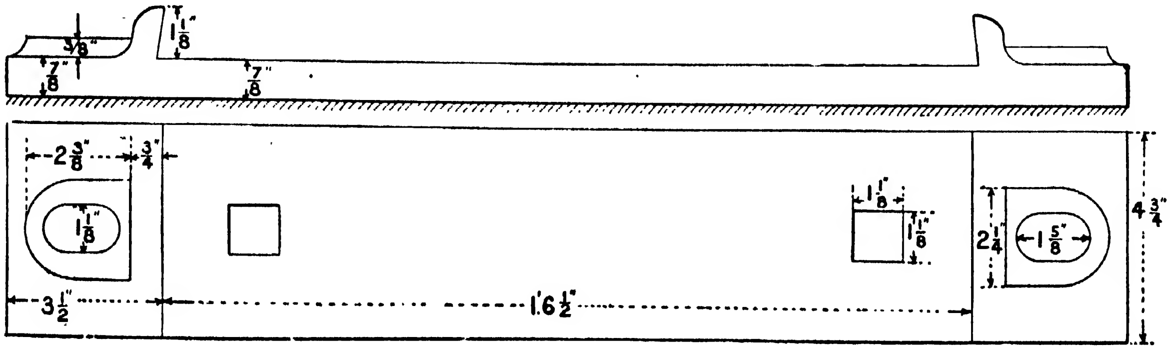


FIG. 138.—Wall Plate.

Hangers. When a shaft is supported from the ceiling of a room, the bearing may take the form shown in Fig. 139. In this arrangement, a suitable cavity is provided, in the central part of the hanger, into which one of the brass steps is fitted. The other step is fitted to the cap, and the whole bolted together.

Various methods are in use to prevent the rotation of the steps, or brasses. Thus, the parts of the steps which are made to fit corresponding parts of the hanger and cap may be made octagonal, rectangular, or circular in form. The first is indicated in Fig. 137. When of a circular form a suitable stop is provided to prevent rotation.

It is only possible to refer to a few of the many kinds of hangers, or brackets, in gene-

instead of the pedestal base being bent round and upwards and fastened on both sides to the ceiling, as in Fig. 139, it may be fastened on one side only and is then known as a *Hanging Bracket*.

Example. Draw the two views of the hanger. Scale 4″ to 1′. (Fig. 139.)

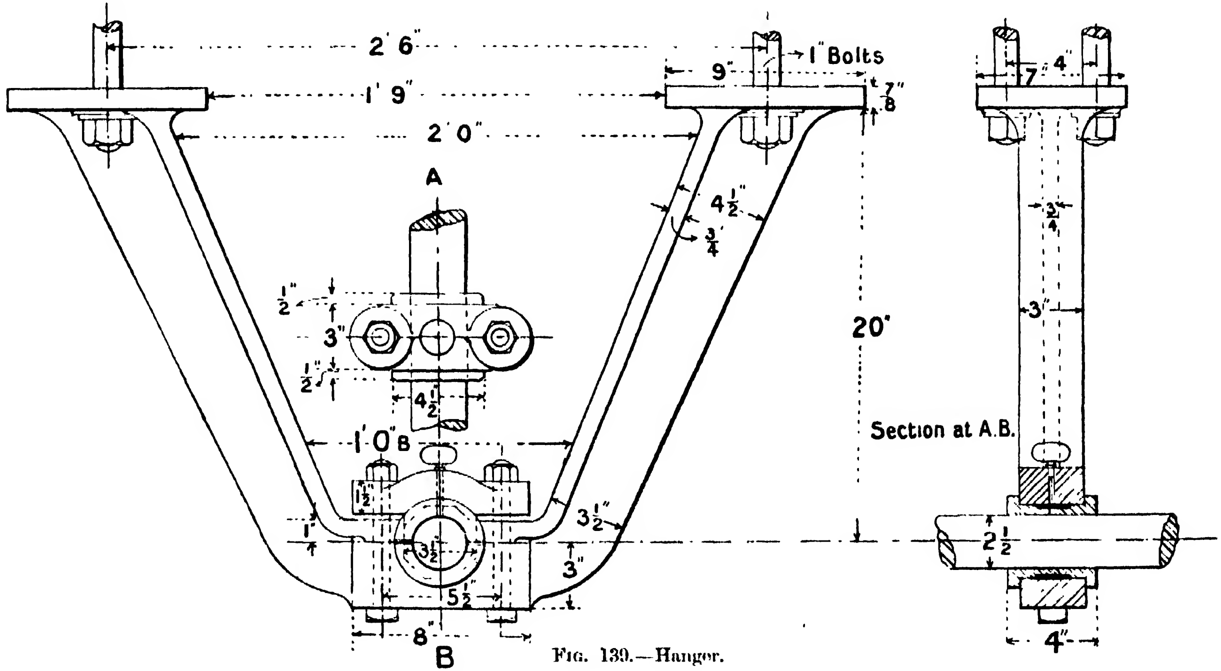


Fig. 139.—Hanger.

A form usually fastened to one side of a pillar and known as a *Pillar Bracket* is shown in Fig. 140. Another form known as a *Wall Bracket*, used for supporting a horizontal shaft parallel to, and at some ·· from, a wall is shown in Fig. 141.

Example. Draw the two views of the bracket (Fig. 140). Scale 6″ to 1′.

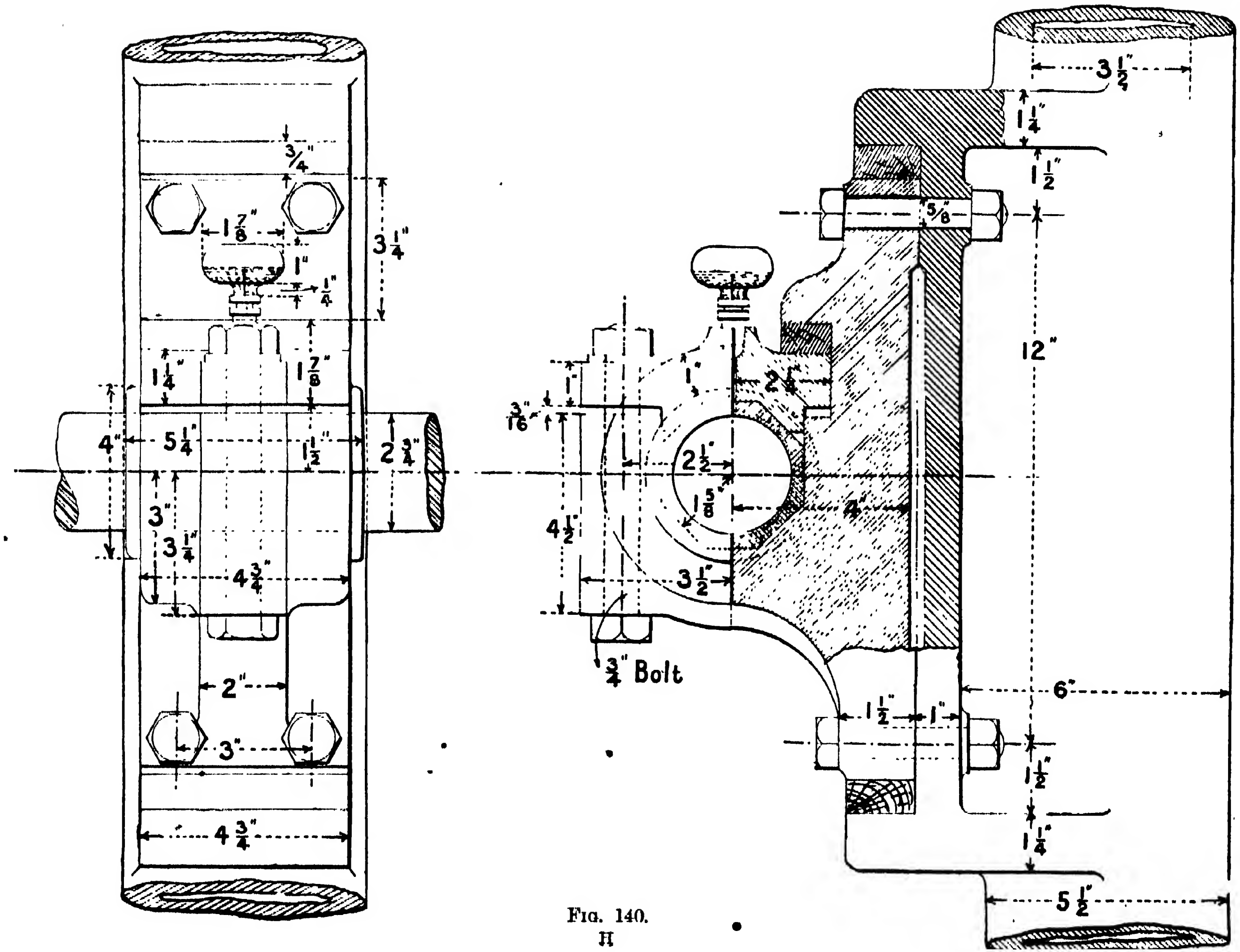

3/4"
3 1/4"
1 7/8"
1"
1/4"
1 1/4"
1 7/8"
4"
5 1/4"
1 1/2"
2 3/4"
3"
3 1/4"
4 3/4"
2"
3"
4 3/4"
1"
3/16"
1"
2 1/2"
1 5/8"
4 1/2"
3 1/2"
3/4" Bolt
2 1/2"
4"
3 1/2"
1 1/4"
1 1/2"
5/8"
12"
6"
1 1/2"
1"
1 1/2"
1 1/4"
5 1/2"

Fig. 140.

Example. Draw the two views of the hanger shown (Fig. 141). Make any necessary corrections in the end view. Scale 6″ to 1′.

Example. A pedestal suitable for this hanger is shown in Fig. 142. Draw this to scale 6″ to 1′, putting all the details into their places in the pedestal, and showing the pedestal in position on the hanger.

Electric motor bearing. The bearings of motors which have to run at high speeds are made in various forms. One is shown in Fig. 143. The bearing is 4 diameters in length, and is supported in a spherical shell. This method allows the shaft to adjust itself, if for any cause it is deviated from its horizontal position. The bearing is of soft metal and the interior is made to contain a supply of oil for lubricating. As indicated in the detailed drawing, two small brass washers rest loosely on the

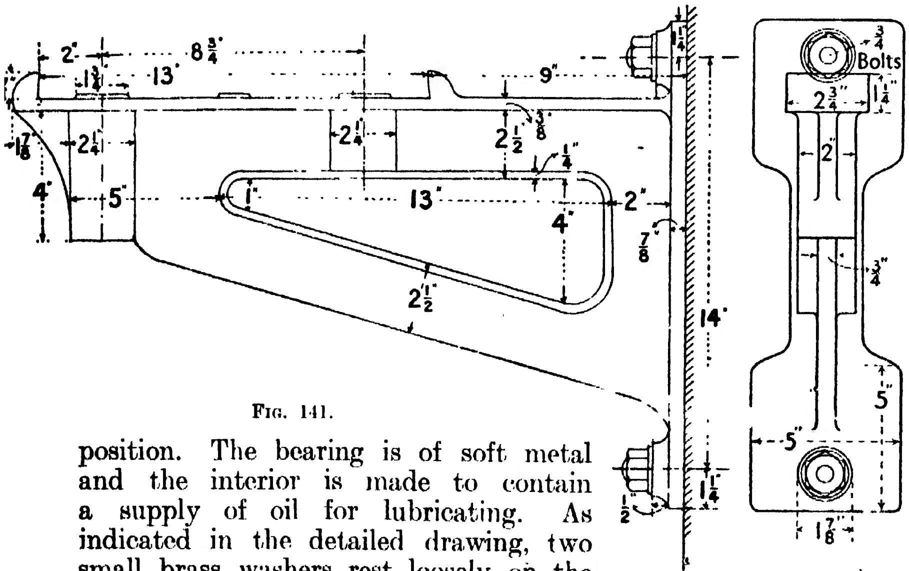


Fig. 141.

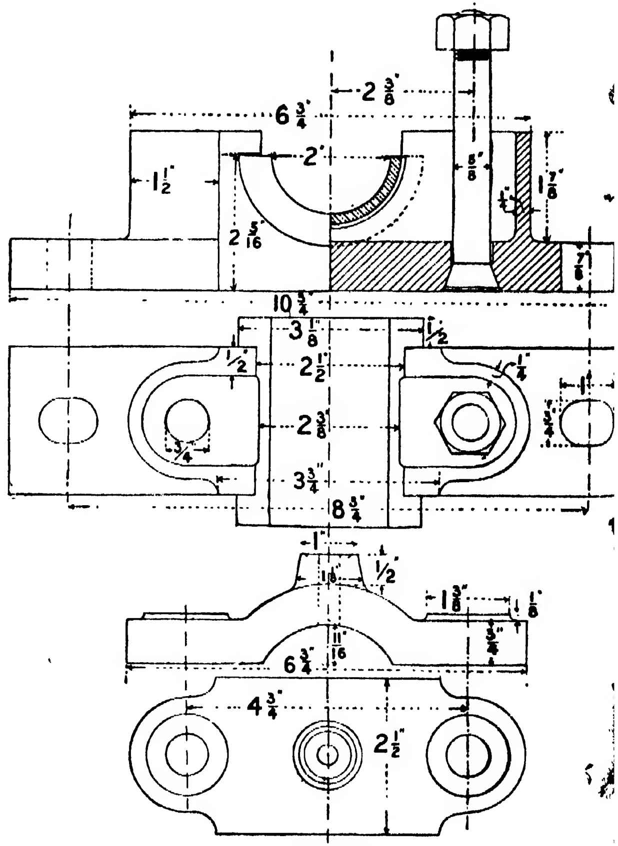
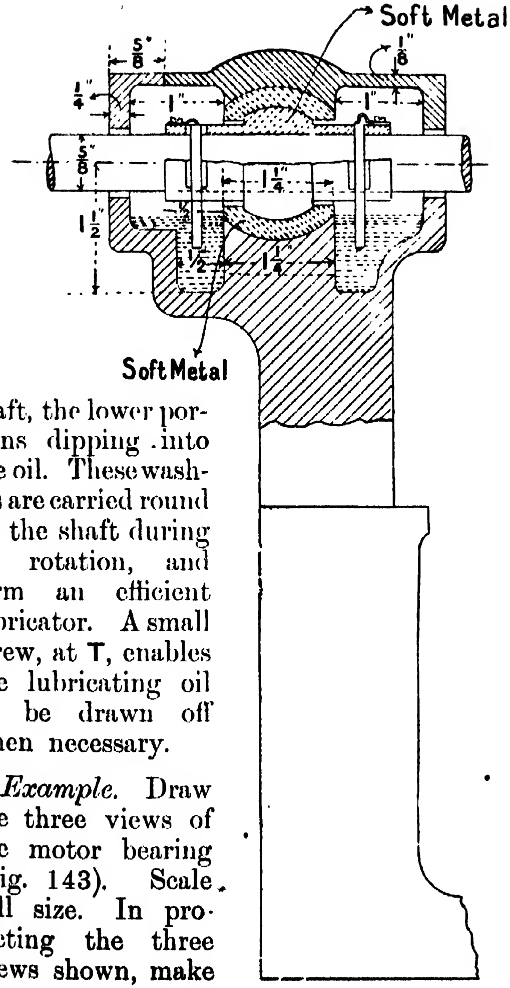


Fig. 142.



shaft, the lower portions dipping into the oil. These washers are carried round by the shaft during its rotation, and form an efficient lubricator. A small screw, at **T**, enables the lubricating oil to be drawn off when necessary.

Example. Draw the three views of the motor bearing (Fig. 143). Scale full size. In projecting the three views shown, make any corrections that

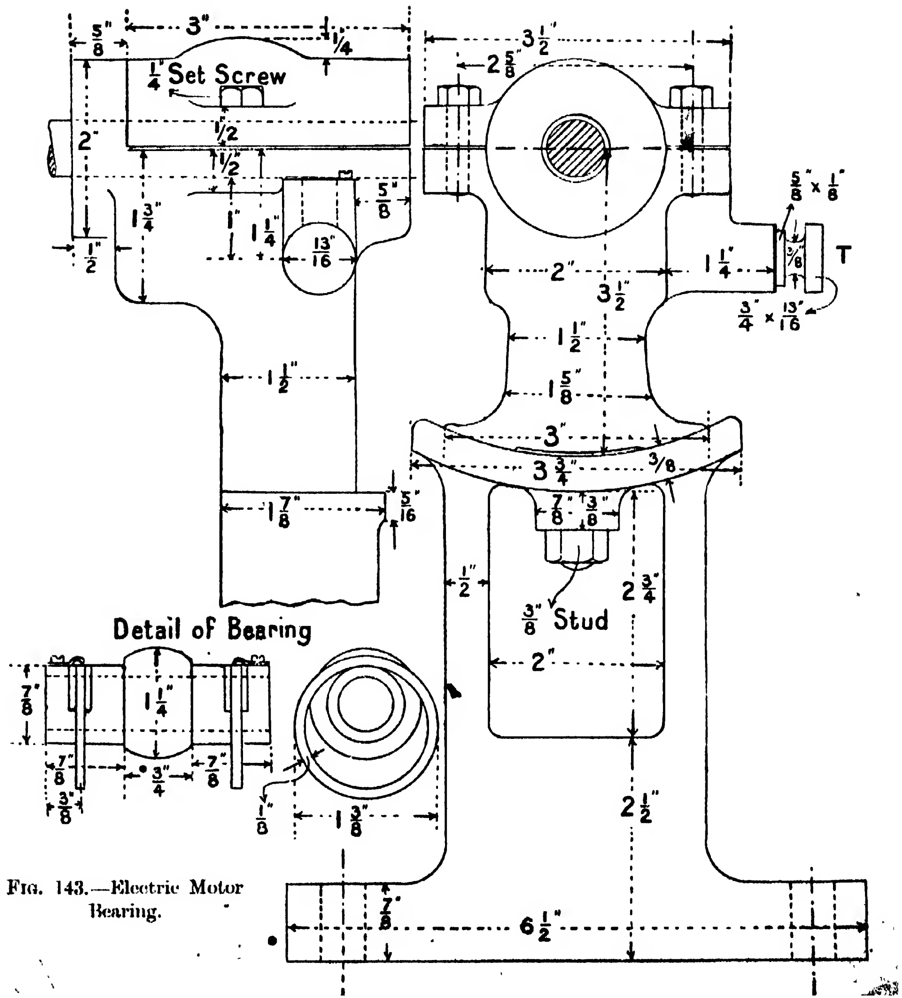


FIG. 143.—Electric Motor Bearing.

Crank shaft bearing. Details of the crank shaft bearing of the horizontal engine (Fig. 172) are shown in Fig. 144.

Example. Draw the two views. Also draw an end view in the direction indicated by the arrow. The distance from the centre of the bearing to the base is $9\frac{1}{2}''$.

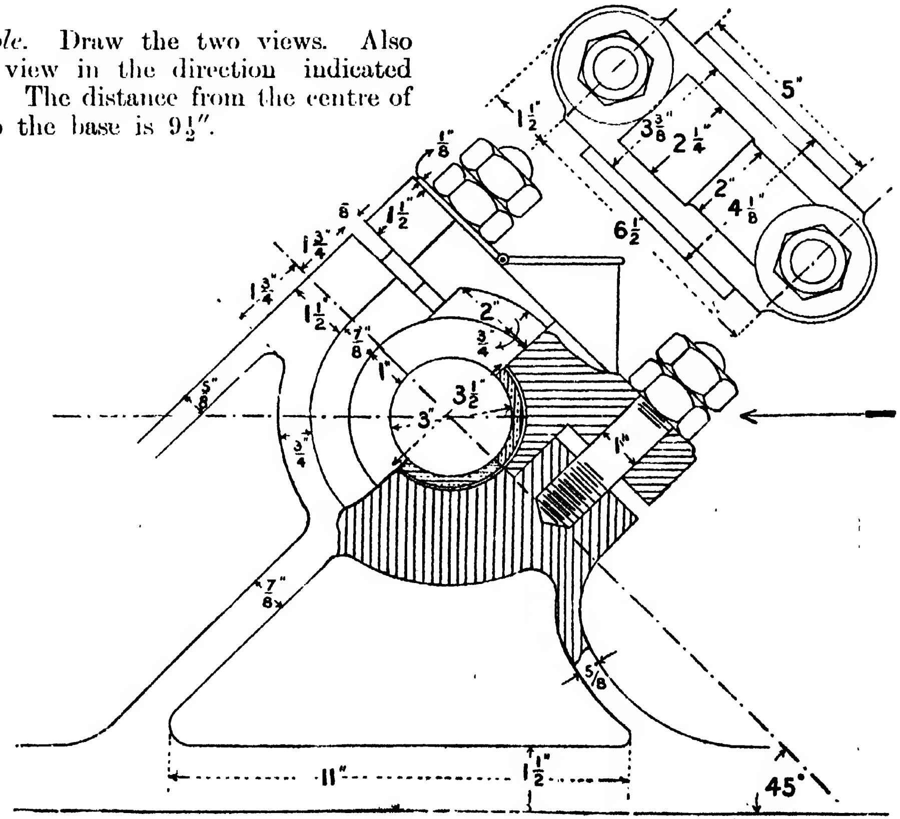
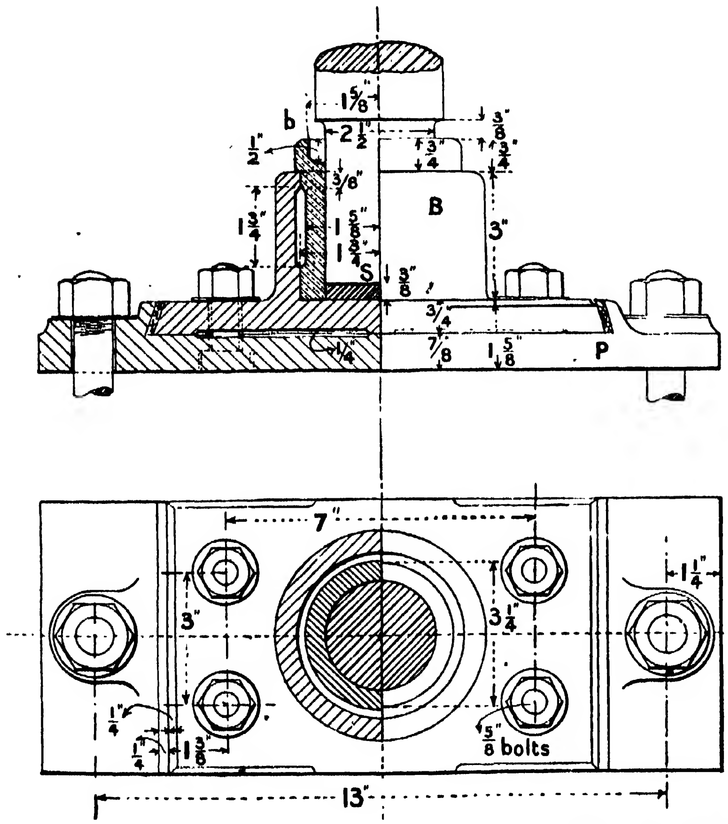
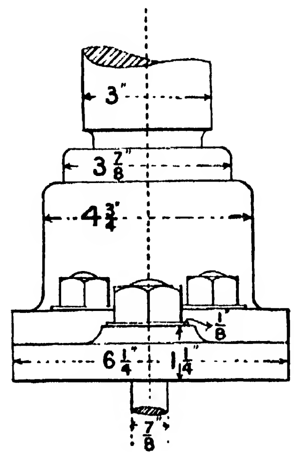


FIG. 144.—Crank Shaft Bearing.

Footstep. When a shaft is vertical, what is called a *footstep bearing* is used. One form of such a bearing is shown in Fig. 145, and consists of a cast-iron block, B, into which a brass bush, *b*, is fitted. The middle portion is usually recessed, as shown, and the bush and the block are in contact for a short distance only at each end. In this manner it is necessary to machine the block and the bush to fit only through two short distances at each end instead of through the whole length. The shaft rests upon a steel





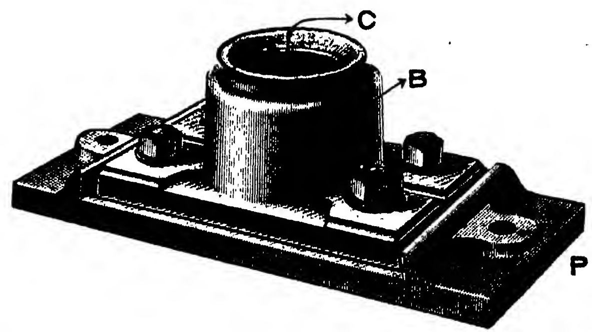


FIG. 145.—Footstep Bearing.

washer, **S**. This washer may be replaced readily when worn. The rotation of the washer is prevented by means of a small steel pin of $\frac{1}{2}''$ diameter.

The bush, as indicated at **C**, is hollowed out to receive and to retain the oil used for lubrication. The block, **B**, and the base plate, **P**, on which it rests, are both provided with chipping strips, and the elongated holes allow for adjustment. When the adjustment has been made, wooden blocks are inserted between the ends of the block and between the projections on the base plate. The perspective view is only inserted to show the relations of the parts **B**, **C**, and **P**.

Example. Draw and complete the two views of a footstep bearing (Fig. 145). Also draw an end view. Scale 6″ to 1′ Make any necessary corrections in the plan.

Ball bearings. In ball bearings a number of hard and accurately formed steel balls are made to run in suitable channels. The radius of the section of such a channel is about two-thirds the diameter of the ball. Such bearings can carry comparatively heavy loads, and the friction is much less than in the forms of bearings already described. The wear of the balls and the friction is very small. One form of such a bearing is shown in Fig. 146.[1]

Example. Draw the two views of the ball bearing (Fig. 146). Scale 6″ to 1′.

EXERCISES. VII.

1. Sketch the brasses for a bearing, and show how they are prevented from turning in the pedestal. [**B.E.**]

2. Sketch one form of hanger suitable for supporting mill shafting. [**B.E.**]

3. A length of shafting is to be carried through a brick wall. Sketch a suitable wall box for the purpose of supporting the shaft. What is the object in using chipping or facing strips?

4. Make a sketch of a simple form of bearing for supporting shafting. Show how the brass bush is prevented from turning. Describe some form of automatic lubricator which will give a regular supply of oil to the bearing. Explain its action and point out any special advantage which it may possess.

[1] Hopkinson, "Electric Lighting Works," *Proc. Inst. of Mech. Eng.*, July 1894.

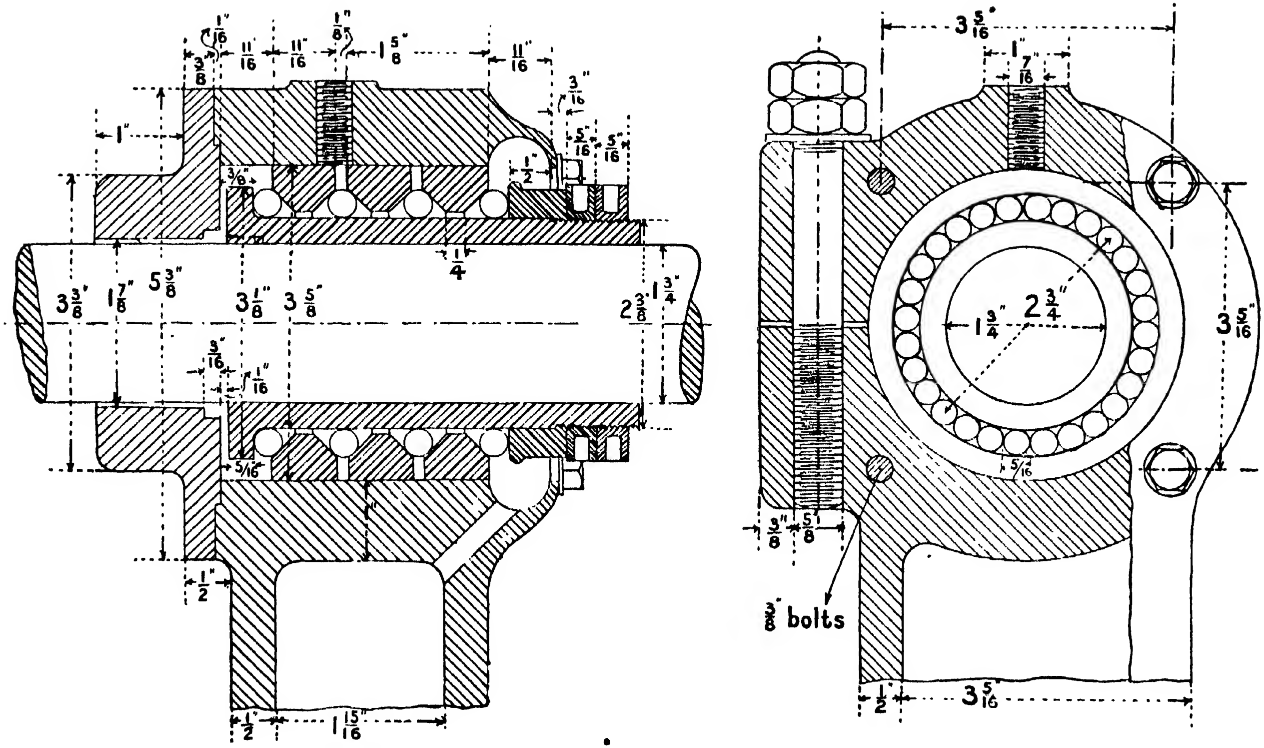


FIG. 146.—Ball Bearing.

5. Sketch and give a description of a bearing suitable for a shaft working under water. State one or two cases in which such a bearing would be used.

6. Sketch two views of a swivel bearing, and state any advantage of this bearing.

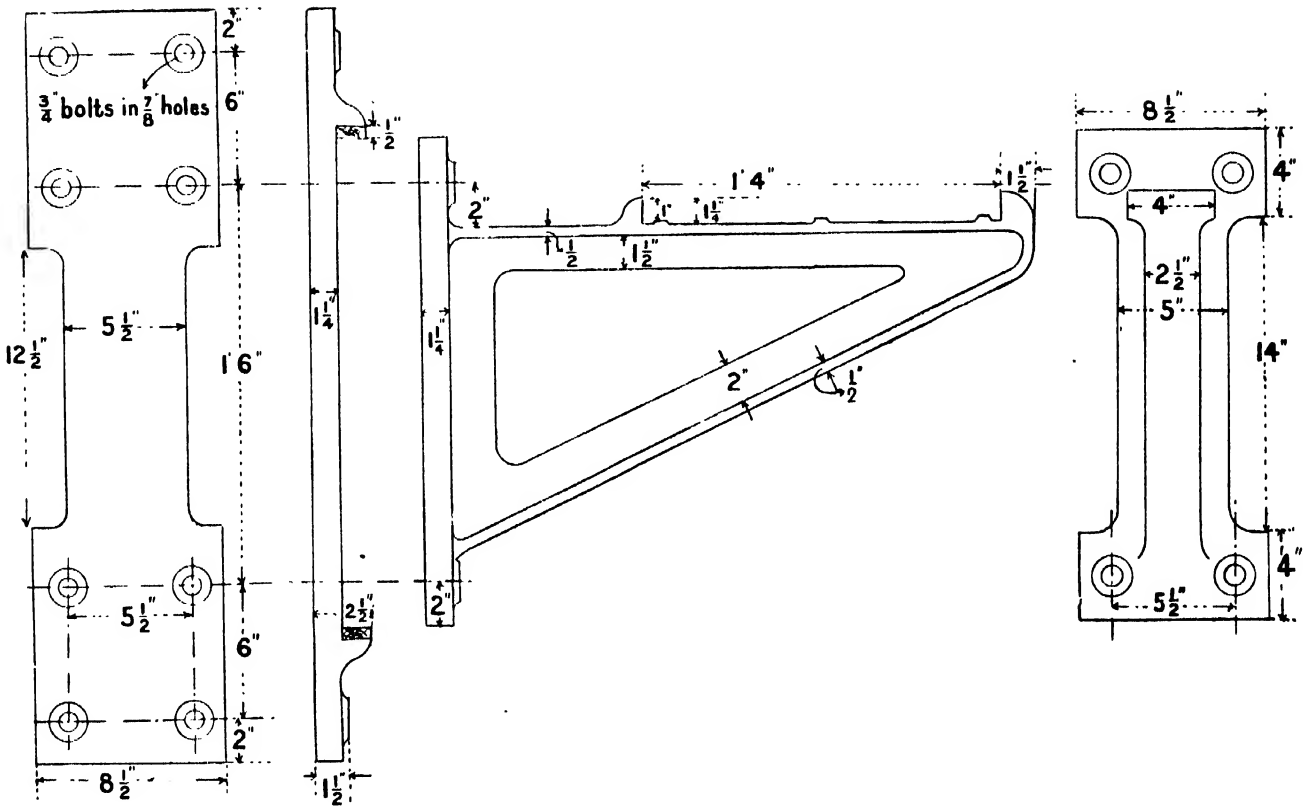


FIG. 147.– Hanger and Wall Plate.

7. Sketch and explain the construction of any form of thrust bearing, showing how provision is made for lubrication.

8. Sketch and describe a form of bearing suitable for the crank shaft of a horizontal engine, complete provision being made for adjustment.

9. Explain by the aid of sketches a method of automatically lubricating: (i) a pedestal for a line shaft; (ii) the end of a small connecting rod; (iii) a footstep bearing.

10. Sketch a footstep bearing suitable for a vertical shaft. Mark on the sketch the materials employed for the various parts.

11. Show, by sketches, a wall bracket. Show how such a bracket may be attached to the wall of a workshop.

12. It is required to extend a length of shafting through a brick wall and support it by means of the wall. With the aid of sketches describe any suitable form of wall box.

13. Show the construction of a crank shaft bearing, provided with means of adjustment for horizontal and vertical wear. [B.E.]

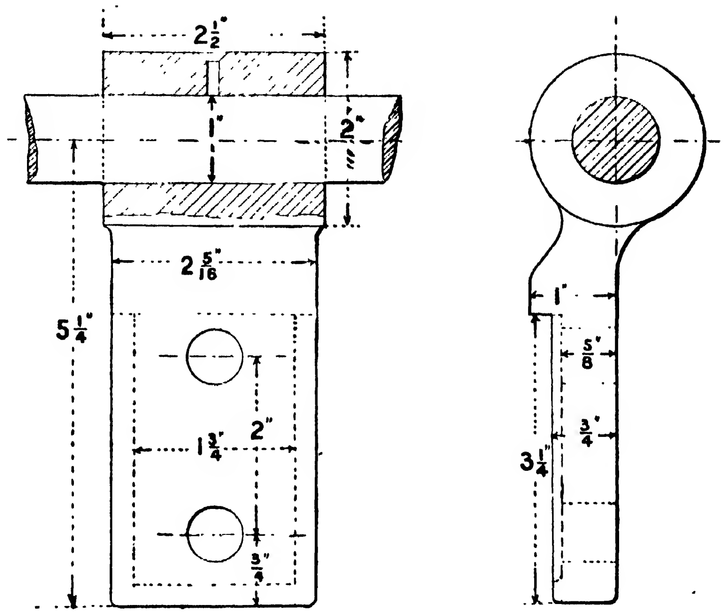


FIG. 148.—Small Bracket.

14. Details of a hanger and wall plate are given (Fig. 147). Do not draw these details separately, but in their respective positions when in place fastened to a brick wall 14″ thick. Scale $\frac{1}{3}$.

15. Small bracket. Draw the two views shown (Fig. 148), also draw a plan. Scale full size.

16. Wall box. Complete the two views shown (Fig. 149). Scale 3″ to 1′. [B.E.]

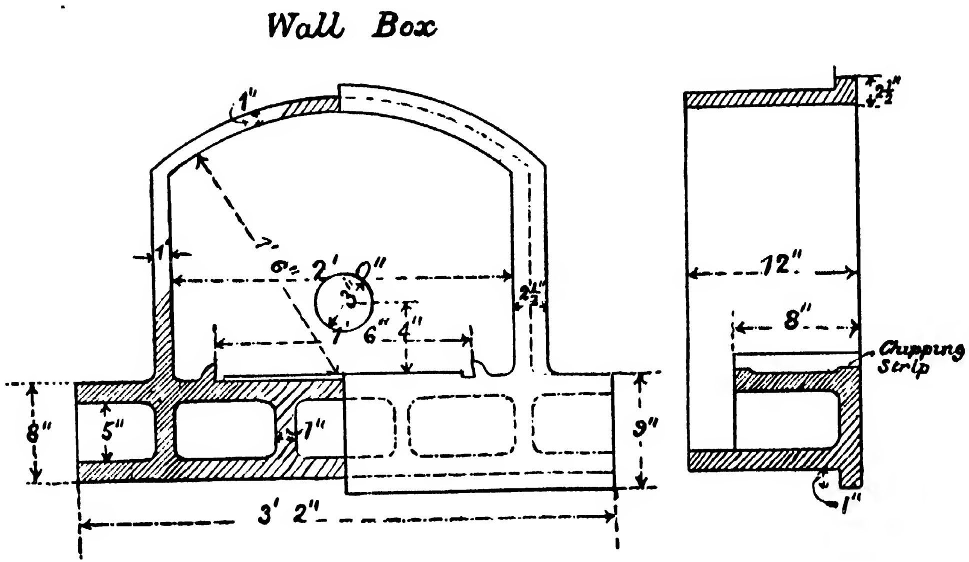


FIG. 149.—Wall Box

17. Tumbler bearing and bracket for the back shaft of a lathe. Draw and complete the two views shown (Fig. 150). Scale full size. [B.E.]

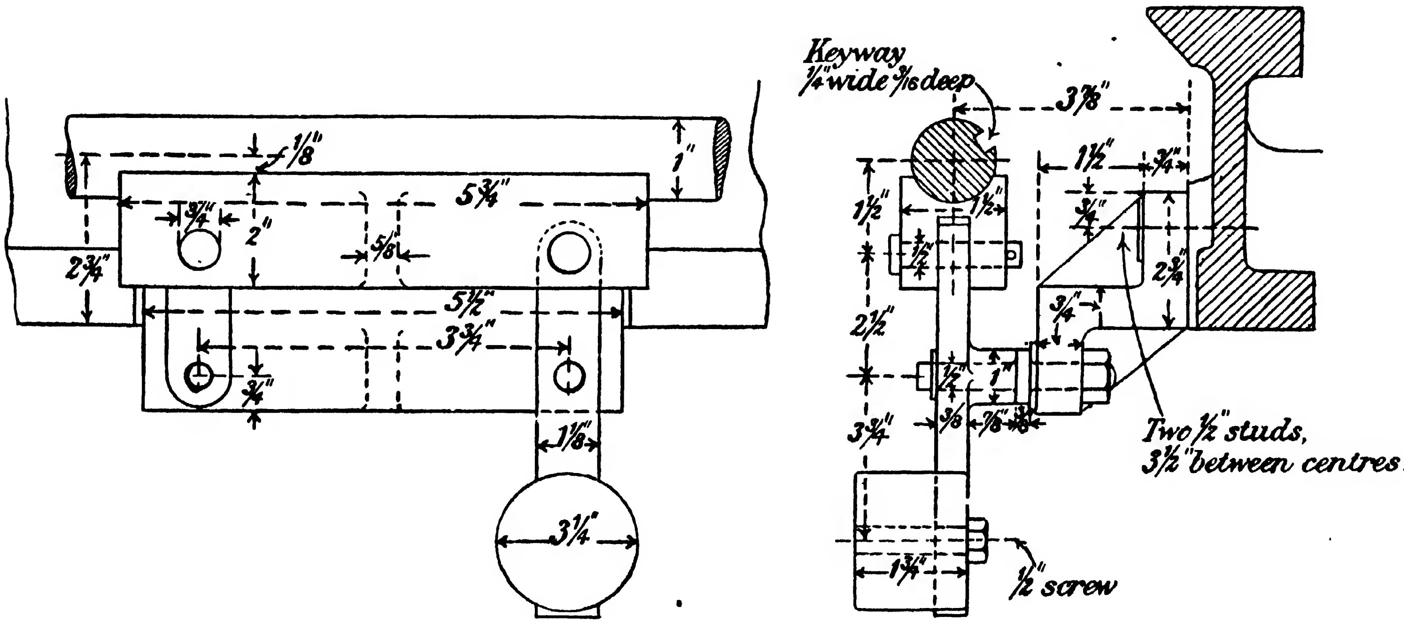
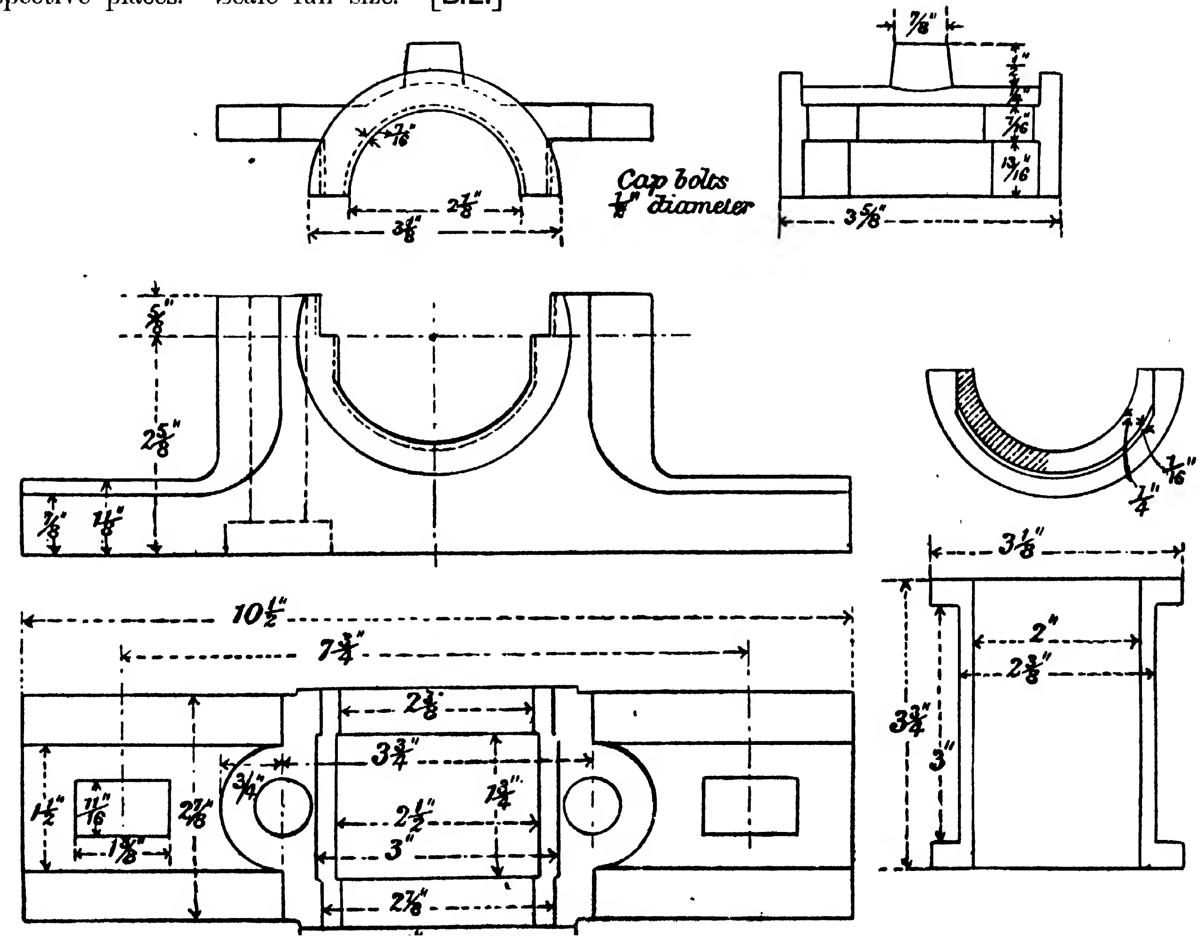


FIG. 150.—Tumbler Bearing and Bracket.

18. Pedestal. Draw elevation, plan, and end view of the pedestal (Fig. 151), inserting the details in their respective places. Scale full size. [B.E.]



19. Side-pedestal. Elevation and plan of a 2″ side-pedestal are given in Fig. 152. Draw these to scale 6″ to 1′.

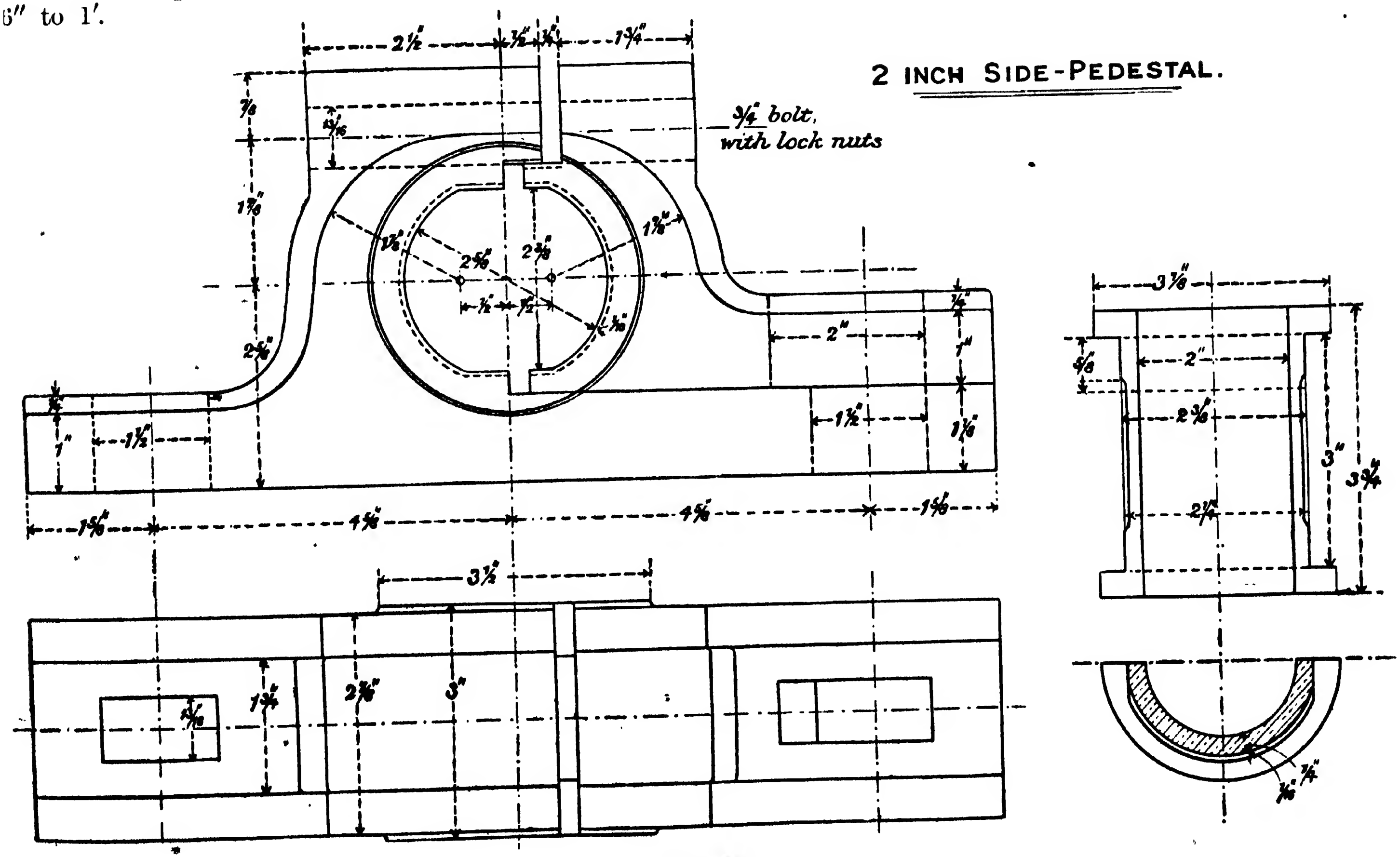


Fig. 152.

20. Crank shaft bearing. Two views of a crank shaft bearing with horizontal and vertical adjustment are given in Fig. 153. Draw to a scale 3″ to 1′.

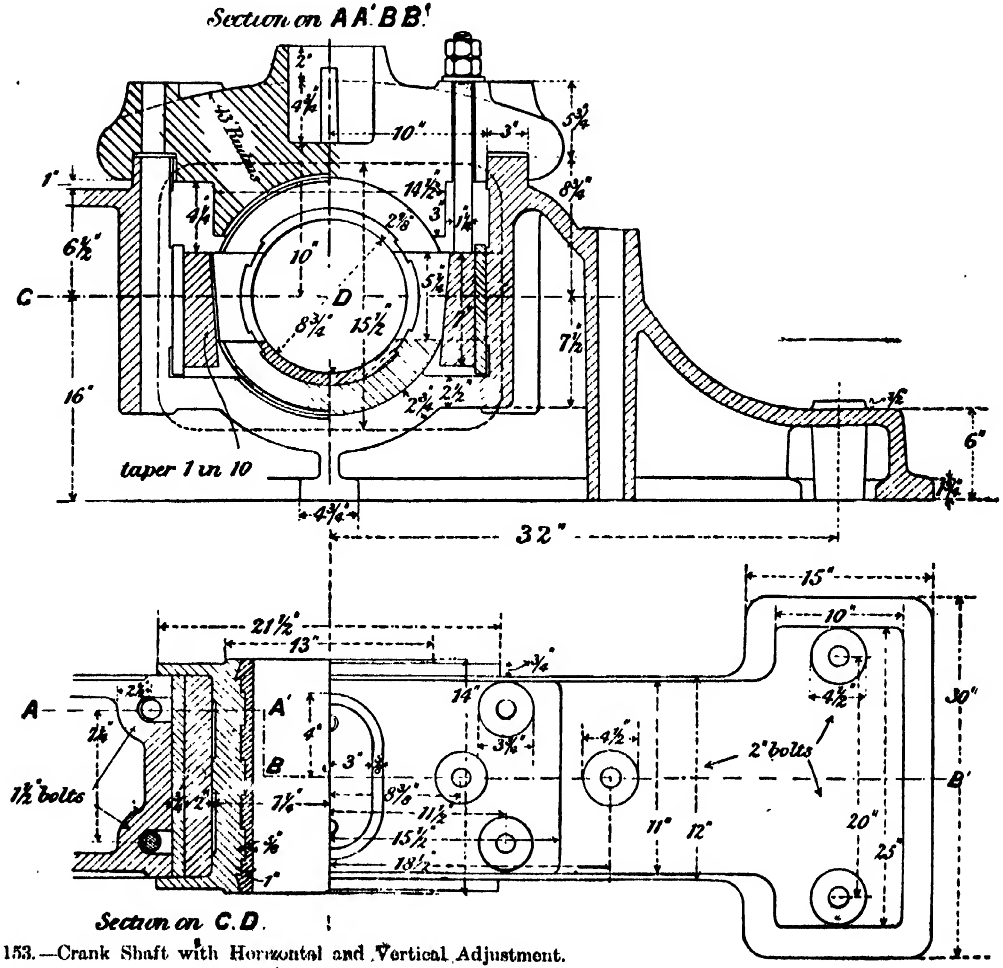
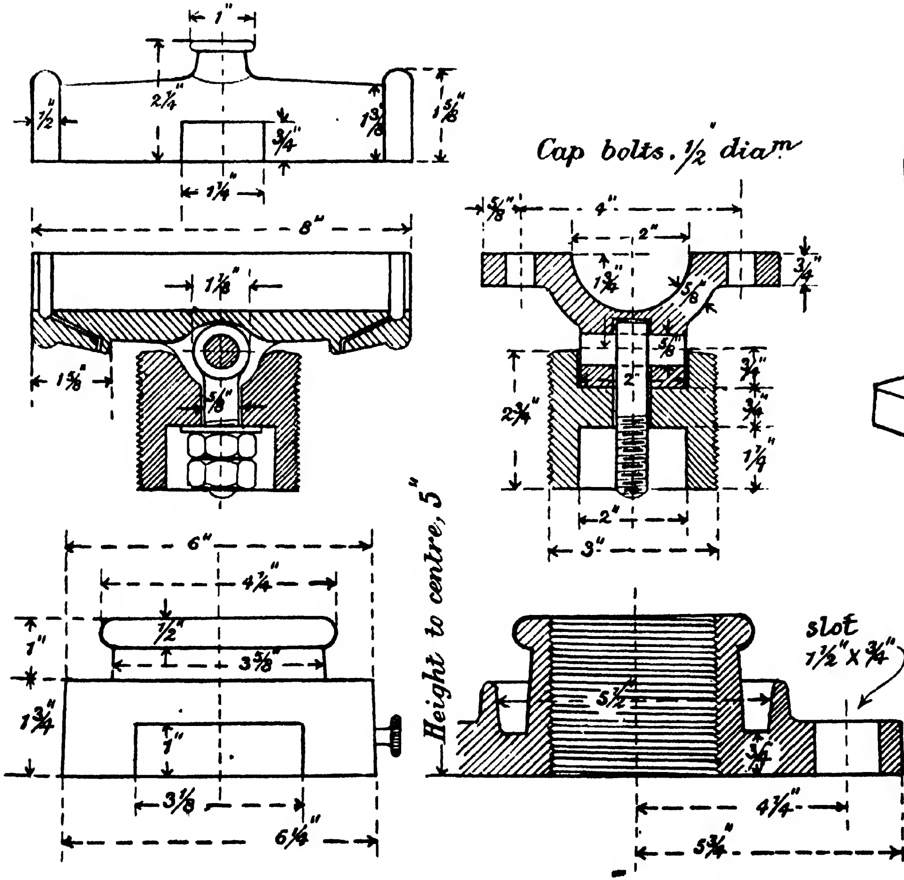


FIG. 153.—Crank Shaft with Horizontal and Vertical Adjustment.

21. Bearing for a shaft. Draw elevation, plan, and end view of the bearing (Fig. 154). Scale full size. [B.E.]



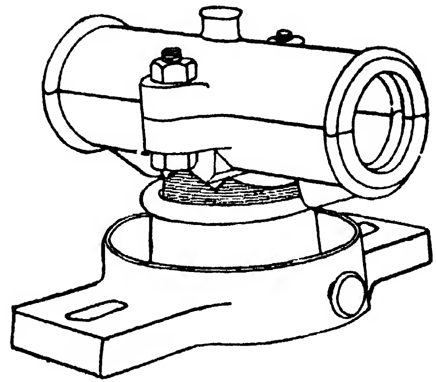
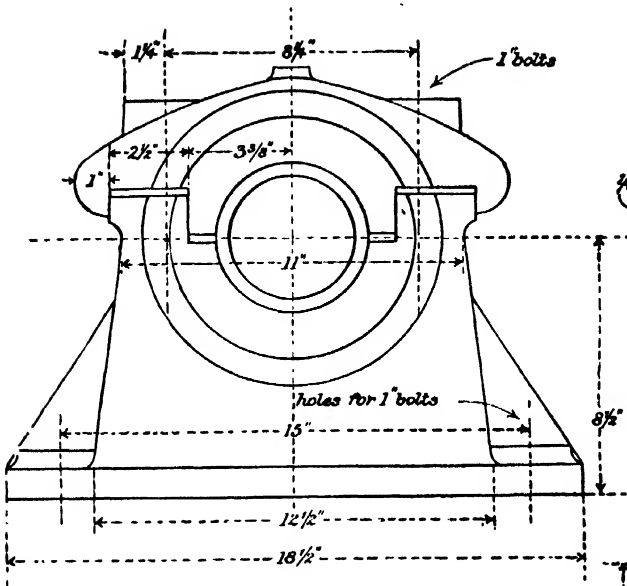


FIG. 154A.

FIG. 154.—Bearing.



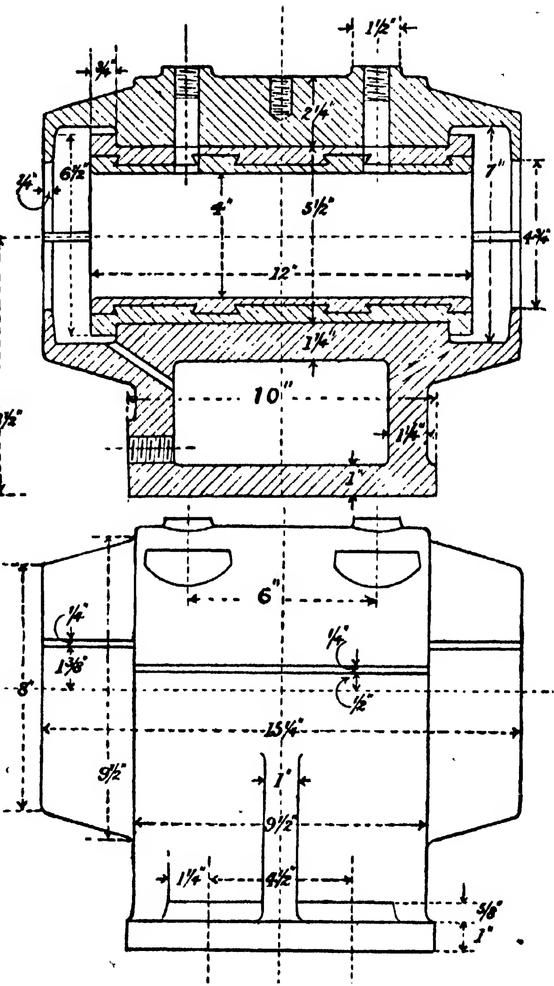


FIG. 155.—Dynamo Bearing.

22. Dynamo bearing. Draw and complete the three views (Fig. 155), also draw a plan. Scale 3″ to 1′.

CHAPTER VIII.

PIPES AND PIPE JOINTS.

Pipes and pipe joints. The materials used for pipes include cast iron, wrought iron, steel, brass, copper, and lead. For convenience in manufacture and in handling, a long length of piping is usually composed of a series of comparatively short lengths, and these separate lengths are fastened together by various kinds of joints. The joint used in any case depends not only on the material but also on the purpose for which the pipe is to be used.

Cast-iron pipes are made easily and cheaply to any desired form; they are made usually in lengths of from 8 to 12 feet. Two forms of joint in general use are the *flange-joint* and the *socket and spigot.* The flange-joint is stronger and easier to connect or disconnect than the socket and spigot, but the flexibility in the latter form of joint makes it suitable for pipes laid in the ground in which changes of level may occur owing to unequal settlement of the soil, etc.

Wrought iron pipes are used to convey gas, water, and steam. They are obtainable from $\frac{1}{8}''$ to $4''$ internal diameter; the separate lengths may be fastened together by means of one of the joints shown in Fig. 159.

Steel is generally used for ordinary and high pressure steam pipes, the longitudinal joint being lap-welded. The plates are not less than $\frac{1}{4}''$ and are usually $\frac{5}{16}''$ thick with $\frac{5}{8}''$ rivets. Cast steel is frequently used for bends and elbows but copper is better and is used in marine and in the best work. The flanges for copper pipes usually consist of hard brass and are brazed to the pipe.

Fig. 156 shows an ordinary form of flange-joint. The ends of the pipes are usually machined in a lathe, and for this purpose a *facing,* as shown, may be provided. This facing is usually about $\frac{1}{8}''$ to $\frac{1}{4}''$ in thickness and about $\frac{1}{2}''$ wide. The joint is made by inserting a ring of india-rubber, millboard, or brown paper smeared with red lead, the flanges being forced together finally by means of bolts or studs. In the former case a portion of the bolt close to the bolt head is made square and is made to fit a corresponding

square hole in the flange somewhat loosely, the object being to prevent the rotation of the bolt during the process of screwing, or unscrewing, the nuts.

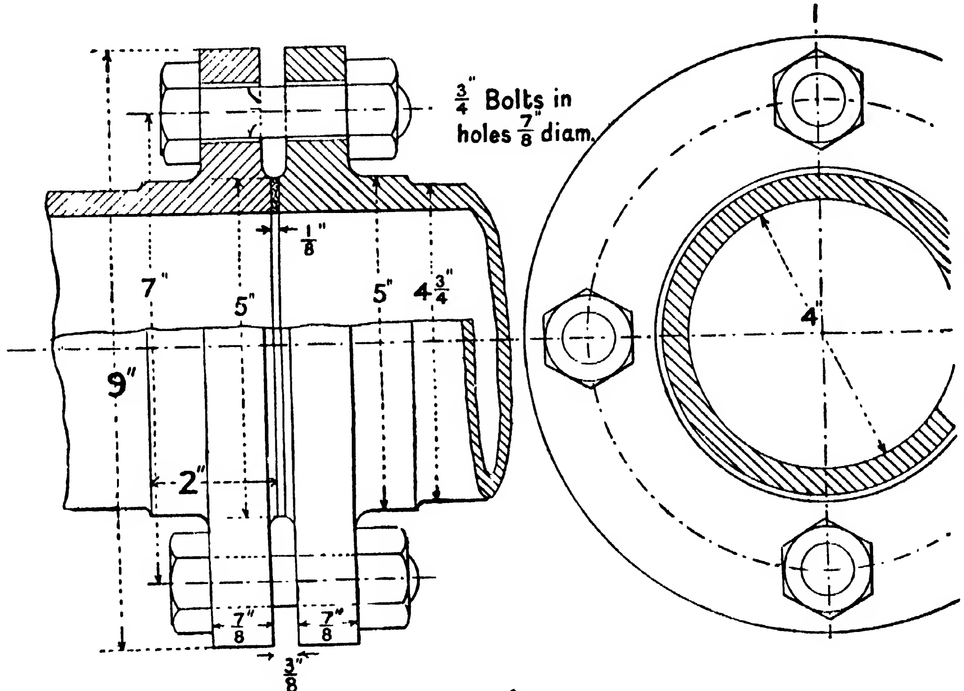


FIG. 156.—Pipe Joint.

Example. Draw full size the sectional elevation and end view of a flange-joint (Fig. 156).

Example. Draw full size the sectional elevation of the pipe joint (Fig. 157). Also draw an end view.

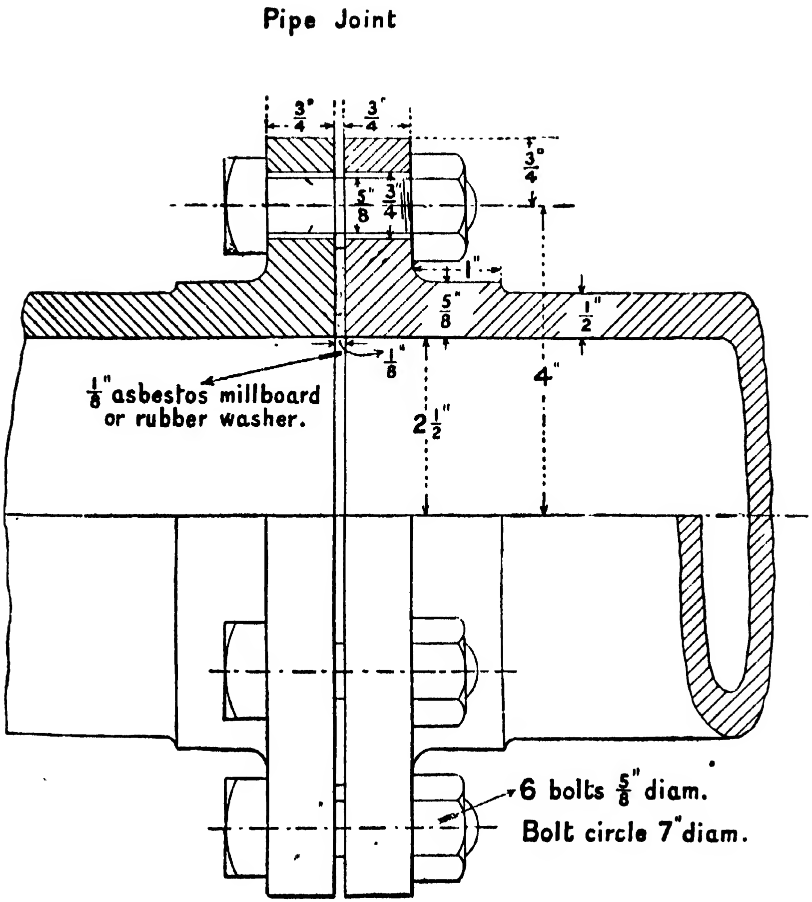


FIG. 157.—Pipe Joint.

Socket and spigot. In this form of joint one pipe is made to enter the other for a short distance as at I (Fig. 158). The joint is made by threading several turns of rope or spun yarn and by pouring molten lead in the space provided between the two flanges. The lead, when sufficiently cooled, may be stemmed in tightly with a hammer and chisel.

Another form of joint is shown at II (Fig. 158), in which a facing about $\frac{5}{8}''$ wide is made slightly taper and to fit a corresponding facing in the socket end. The joint is made by smearing the surfaces in contact with red lead and forcing them together.

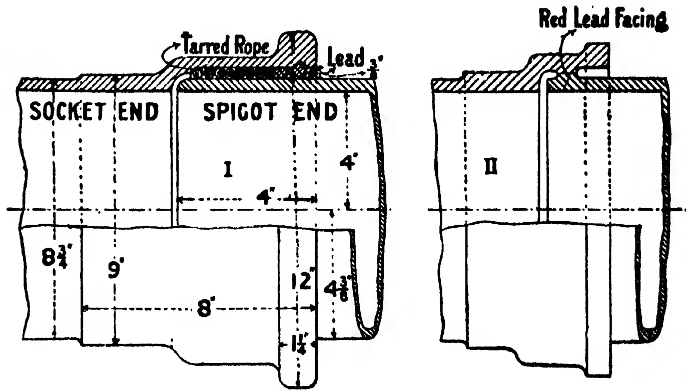


FIG. 158.—Socket and Spigot Joint.

Wrought-iron pipes. In wrought-iron pipes of comparatively small size the joint may be made by screwing what is called a *coupling*, shown at **C** (Fig. 159), on the end of one pipe **A** and screwing the other into it. In some cases it is important that the surface of the pipe shall be free from projections, and a *nipple* **N** (Fig. 159) may be used. The ends of the pipes are screwed on to the nipple until they meet at the centre. The objection to this form of joint is that when the pipe is used to convey water or

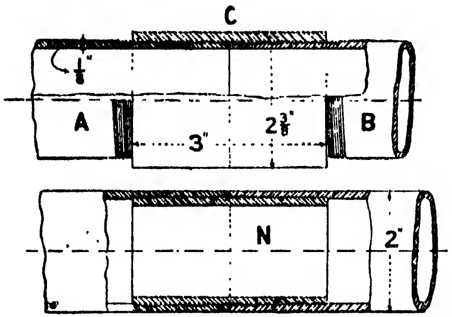


FIG. 159.—Wrought-iron Pipes.

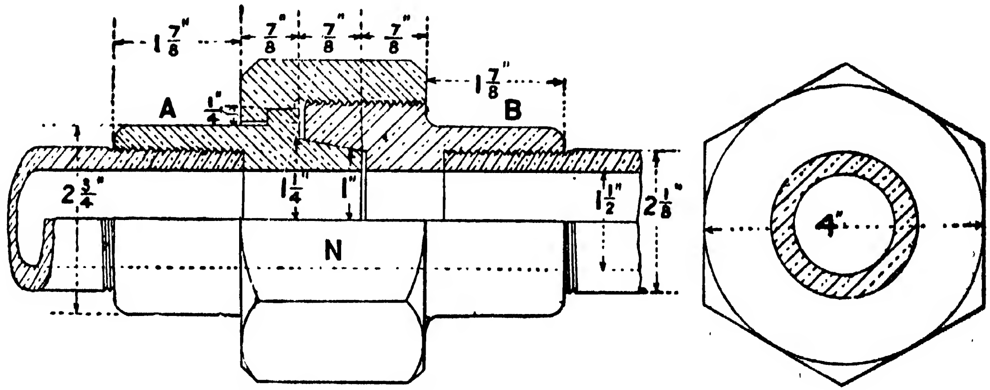


FIG. 160.—Union Joint.

other fluid the projecting surface of the nipple may cause a partial stoppage. For pipes of larger size a cast-iron flange may be riveted on to the end of each pipe.

Union joint. A *union joint* is a very useful and handy joint for steam or other pipes of comparatively small size, since it is easily connected or disconnected and makes a steam-tight joint.

The two parts, **A** and **B**, (Fig. 160) are screwed to the end of the pipes; the part **A** is coned and ground to fit accurately a corresponding inclined surface on **B**. A hollow hexagonal nut **N** is slipped over

the part **A** and fits an external screw on **B**. The two cone surfaces may be drawn tightly together by rotating the nut **N**, thus forming a steam or water-tight joint.

Example. Draw full size the two views of the union joint (Fig. 160). Also draw a plan.

Lead pipes. The joints used in lead pipes are generally either a *wiped joint* (Fig. 161) or a *blown joint* (Fig. 162). In the wiped joint the end of one pipe is opened, or *tamped out*, and the end of the other *rasped* to a sharp edge.

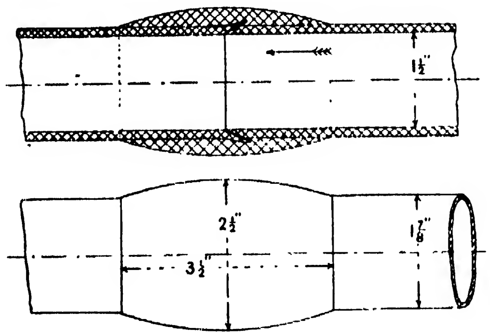


Fig. 161.—"Wiped Joint" for Lead Pipes.

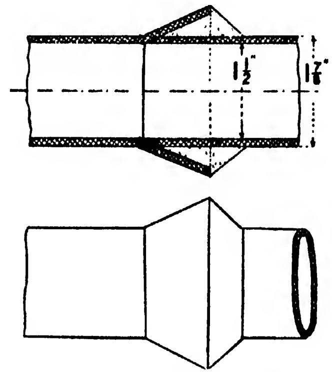


Fig. 162.—"Blown Joint" for Lead Pipes.

The pipes are fitted together and the two ends *shaved* bright for a distance of about 1½ in. Molten solder is poured on the joint and the joint wiped with a piece of greased cloth ; the solder adheres to the bright surface and forms a sharp line round the pipe. The arrow denotes the direction of the flow.

In a blown joint the end of one pipe is enlarged to receive the end of the other and the joint is made by using a *blow-pipe*..

Hydraulic pipe joint. The joints already described would be entirely useless for the pipes conveying water at high pressure necessary in hydraulic work. Thus, for general hydraulic purposes, the pressure of

the water may be 700 lbs. per square inch and in the case of machine tools may reach 1500 lbs. per sq. in. One form of joint which is suitable for cast-iron pipes is shown in Fig. 163.

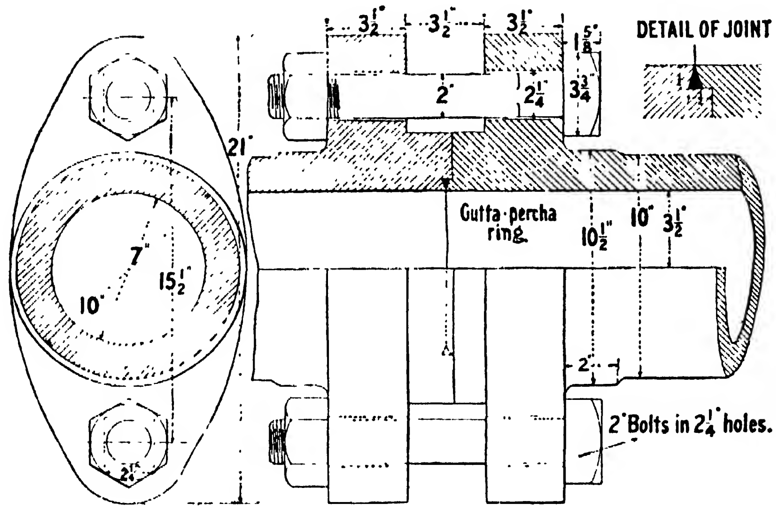


Fig. 163.—Hydraulic Pipe Joint.

At the end of each pipe there is a strong elliptical flange with two bolt holes. One pipe enters the other for a short distance, forming a dove-tailed recess, and the joint is made by a gutta-percha ring ¼″ diameter.

Example. Draw the sectional elevation and end view of the hydraulic pipe joint (Fig. 163). Scale 6″ to 1′. Also draw a plan.

The preceding arrangement is modified in the case of wrought iron or steel tubes which are used to supply water to machine tools. The ends of the pipes are screwed to a gas thread and elliptical cast-iron flanges are screwed on.

Example. Draw the two views of the hydraulic pipe joint (Fig. 164). Also draw a plan. Scale 6″ to 1′.

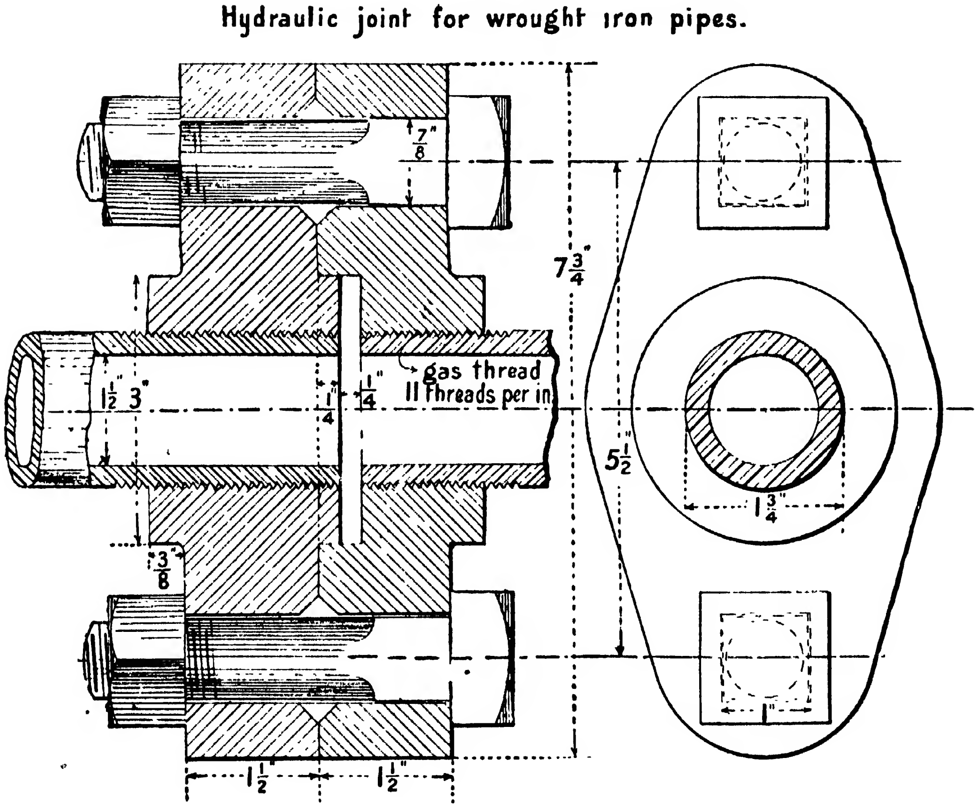


FIG. 164.

Fig. 165 shows a sectional elevation of a *steel steam pipe joint.* The ends of the pipes are screwed to a gas thread and two collars **BB** are screwed on and afterwards brazed. The joint is made by a copper ring pressed tightly against the collars by means of bolts passing through two loosely fitting wrought-iron collars **CC.**

Example. Draw a sectional elevation and end view of the pipe joint (Fig. 165). Scale 4″ to 1′.

Tank joint. Two forms of joint suitable for a tank are shown (Fig. 166) at **A,** the space $\frac{1}{4}''$ between the

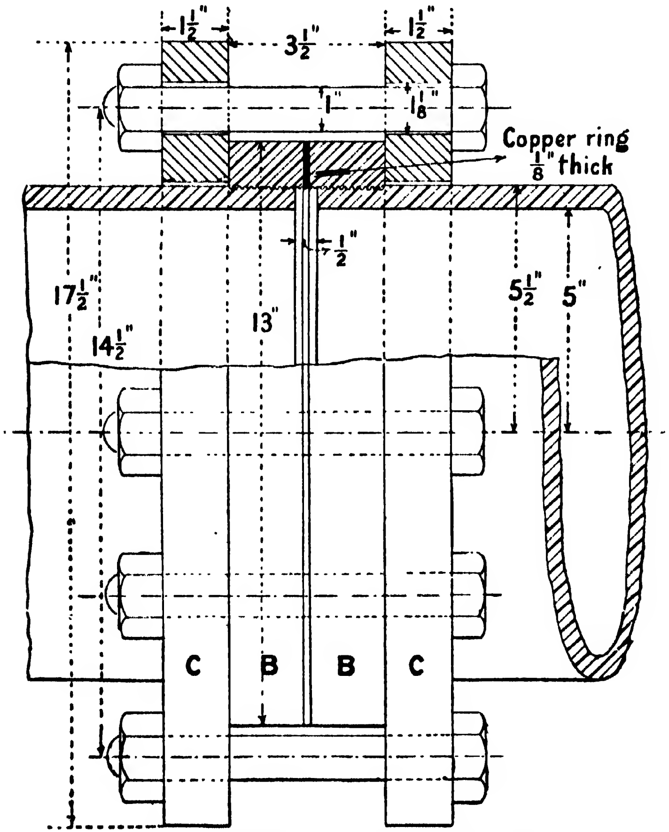


Fig. 165.—Hydraulic Pipe Joint (Steel Pipes).

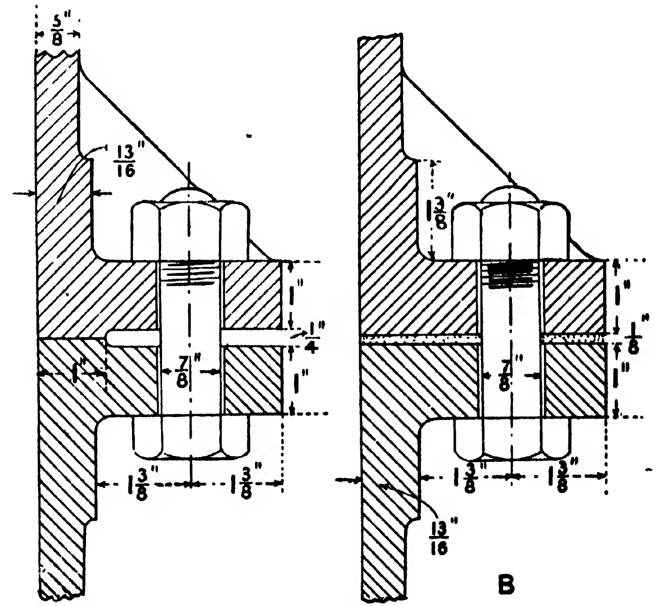


Fig. 166.

two flanges is filled with iron borings mixed with sal ammonia and rammed tightly into the joint. This arrangement is called a *rust joint*. At **B** the joint is made by using a strip of asbestos or millboard. Flanges are sometimes stiffened by ribs or gussets, as shown in Fig. 166. Thickness 1·1**t**, where **t** is thickness of pipe in inches.

Expansion joints. Metal pipes expand and contract with variations in temperature. Thus, steam pipes are found to alter in length about 1 inch in 50 feet, the range of temperature being about 140° C. Various forms of expansion joints are used to allow for this movement.

As indicated in Fig. 167, a brass liner may be fitted to one end of one pipe and the pipe be made to slide easily in a form of stuffing box. Leakage at the joint is prevented by packing inserted in the space **P**. This packing is forced against the sliding surfaces by means of the bolts shown.

The stuffing box would be of simpler form for pipes of comparatively small size and a brass liner would not be used.

Example. Draw the sectional elevation of an expansion joint, Fig. 167. Also draw an end view. Scale half size.

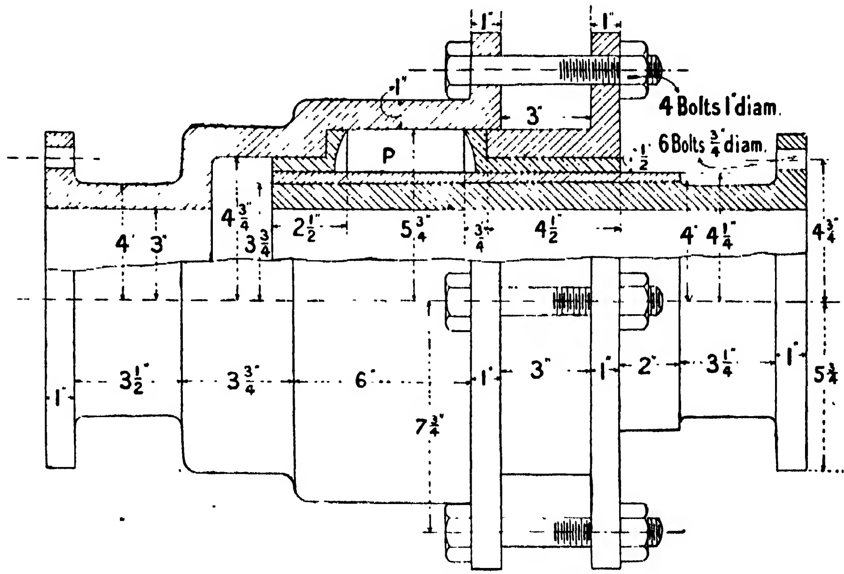


Fig. 167.—Expansion Joint.

Strength of cylinders. In pipes and cylinders in which the thickness of the metal is comparatively small, as in the shell of a steam boiler, the relation made use of is $p \times d = 2f \times t$, where **p** denotes the internal pressure in lbs. per sq. in., **d** the diameter of the cylinder in inches, **f** the tensile strength of the material in pounds per square inch, and **t** the thickness in inches. The preceding formula is not applicable in the case of the cylinders employed for hydraulic pressures and usually called *thick cylinders*.

If **R** is the external and **r** the internal radius of such a cylinder, **p** the internal pressure, and **f** the

safe working stress of the material = 2700 lbs. per sq. in. for cast iron, then **R** and **r** are connected by the relation

$$R = r\sqrt{\frac{f+p}{f-p}};$$

when **r** is known, **R** can be calculated.

Example. In a hydraulic accumulator **r** is $4\frac{3}{4}''$. The internal pressure is 1000 lbs. per sq. in.

$$R = 4\tfrac{3}{4}\sqrt{\frac{2700+1000}{2700-1000}} = 7''.$$

Hence, the thickness of metal is $7 - 4{\cdot}75 = 2\frac{1}{4}''$.

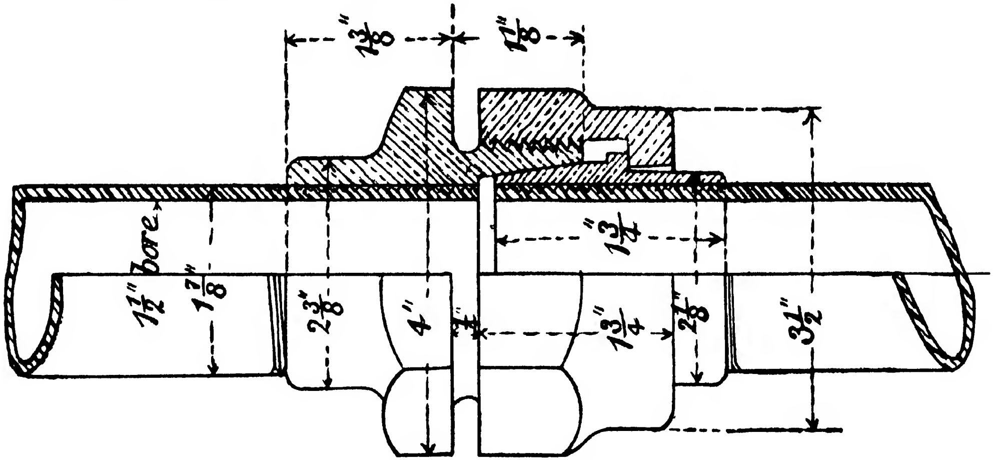


FIG. 168.—Pipe Joint.

EXERCISES. VIII.

1. Union nut and joint for connecting two lengths of small piping, Fig. 168. Draw an end view and a plan. [B.E.]

2. With the aid of sketches, describe how to make a steam-tight joint between two flanges. Explain in what circumstances studs are used instead of bolts. [B.E.]

3. Show, by sketches, the methods of constructing the ends of wrought iron or steel pipes to facilitate their connection. [B.E.]

4. Describe with a sketch how the joints in hydraulic pipes are made to resist, without leakage, the high pressures used.

5. Show, by sketches, two methods of joining wrought-iron and cast-iron pipes.

6. Show, by sketches, the construction of a socket joint suitable for connecting lengths of piping.

7. Name the principal materials of which pipes such as are usually employed by engineers are made.

8. Hydraulic pipe joint, Fig. 169. Draw full size, also draw a plan. Explain how the joint is made water-tight. How are the bolts prevented from turning in the bolt holes? [B.E.]

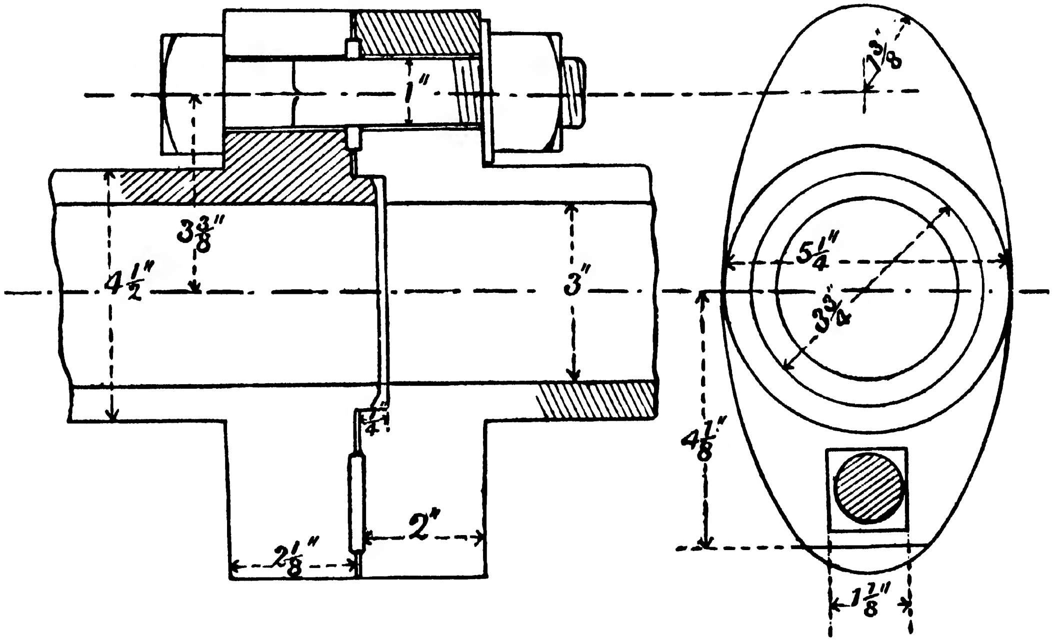


FIG. 169. Hydraulic Pipe Joint.

9. Find the thickness of the steel shell plates of a steam boiler; diam., 7 ft. 6 in., pressure, 125 lbs. per sq. in.; tensile strength of material, 30 tons per sq. in.; factor of safety, 5; efficiency of joint, 70 per cent.

10. A cast-iron pipe is jointed by means of flanges 10 in. diameter. 1 in. thick. The pipe is 4 in. internal diameter and is $\frac{3}{4}$ in. thick. Each joint has five $\frac{7}{8}$ in. bolts joining the two flanges. Draw section and an end view of the joint. Scale $\frac{1}{2}$.

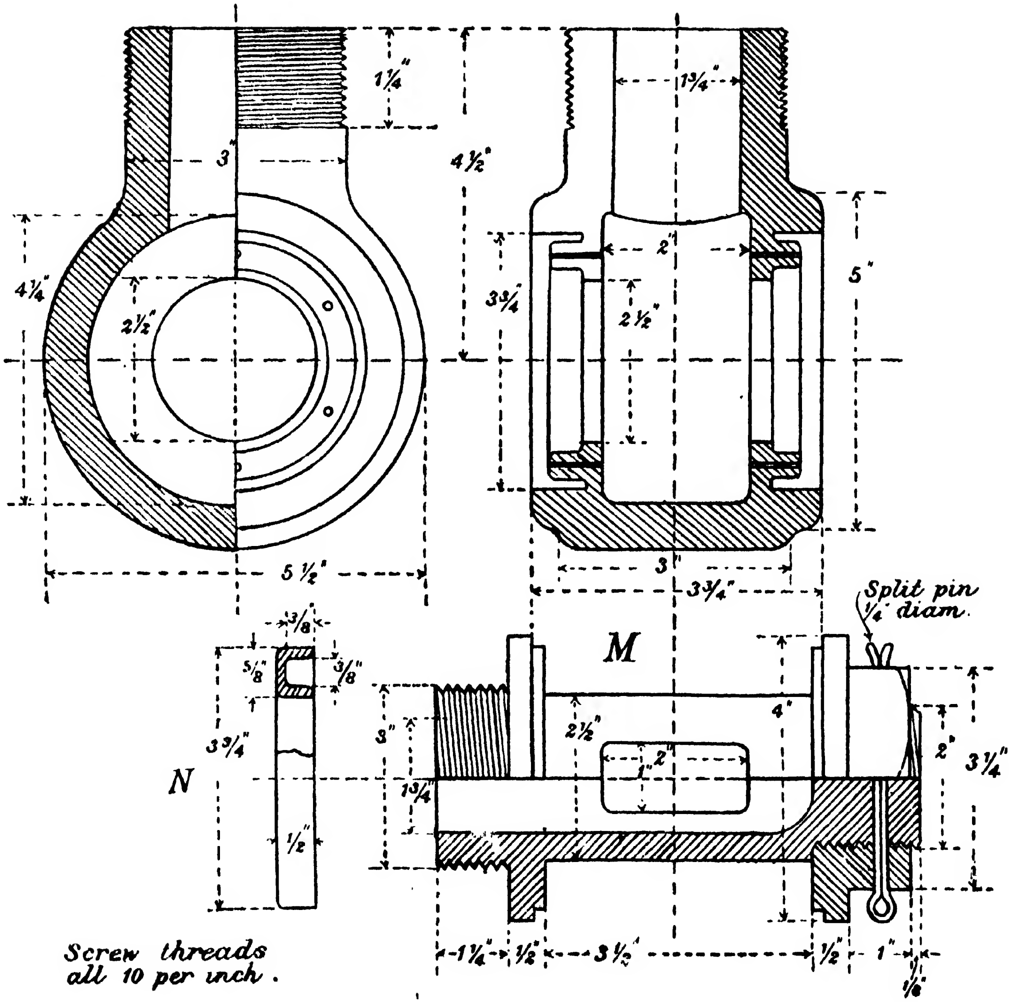


FIG. 170.—Hydraulic Pivot Joint.

11. Give sketches and a description of some method of providing for the expansion and contraction of a long length of steam pipe. [B.E.]

12. With the aid of sketches, describe how to make a steam-tight joint between two flanges. What are the conditions used to determine the most suitable diameter and number of bolts to use? [B.E.]

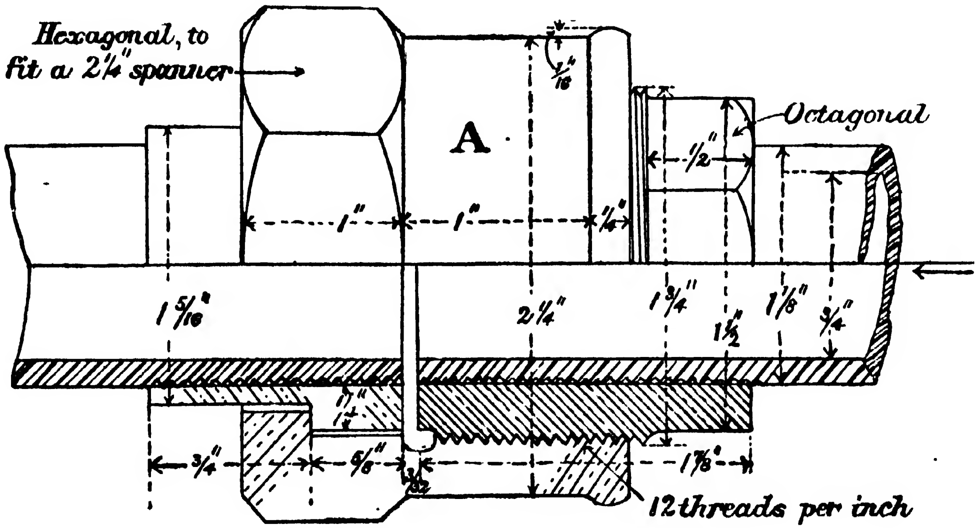


FIG. 171.—Union Joint for Hydraulic Pipes.

13. Give sketches showing two ways of constructing pipes from rolled steel plates so that two lengths may be readily connected with a water-tight joint.

14. Draw the sectional elevation of the hydraulic pivot joint in Fig. 170. Scale full size. Draw also an end view. **M** shows the plug and retaining nut half in section, and **N** is a cup-leather. [B.E.]

15. Fig. 171 shows a form of union joint suitable for hydraulic piping. Draw two views of the joint. Scale full size. Also draw a plan projected from **A**. [B.E.]

CHAPTER IX.

ENGINE DETAILS. PISTONS.

Engine details. In considering the details of an engine, it is important to know the relation of any single detail to the whole. One of the simplest forms of engine is a horizontal or direct-acting engine. In Fig. 172 it will be seen that the piston rod is fastened at one end to the piston and at the other to the crosshead, the connection between the crosshead and the crank is made by means of a connecting rod.

The pressure of the steam acting on alternate sides of the piston gives a to and fro motion to the piston in the cylinder, and this rectilinear motion causes rotation of the crank and the crank-shaft, to which it is fastened.

The piston rod, connecting rod, and crank, are all in one line when the piston is in its extreme position to the right, or to the left; these positions or points are known as *dead points* and occur twice in each revolution of the crank. Means have to be provided to enable the mechanism to get past these points, and this is effected by means of a fly-wheel, *i.e.* a wheel of comparatively large radius and with a heavy rim. When a fly-wheel is not admissible, two cylinders are provided and the pistons are connected to two cranks mutually at right angles. A similar arrangement is used also in engines which have to be reversed, such as in locomotives, portable engines, etc.

A most instructive exercise for those who have not access to an engine of the kind referred to is to make a simple skeleton model in wood or cardboard.

The admission of steam to one side or other of the piston is effected by means of a *slide valve.*

The distance moved through by the piston from one end of the cylinder to the other is called *the stroke*, or *the travel* of the piston. This distance is obviously *twice* the *throw of the crank* (the name given to the distance between the centres of the crank pin and the crank shaft).

The crosshead is made to move in a straight line parallel to the axis of the cylinder by means of suitable *guides* or *guide bars.* These guides may form a segment of a circle as in Fig. 192, or be flat as

in Fig. 190. Only one such surface is necessary in an engine in which the crank shaft rotates in one direction only. When the crank shaft rotates in both directions, as in all reversing engines, locomotives, etc., two surfaces, one on the upper and the other on the lower, must be provided.

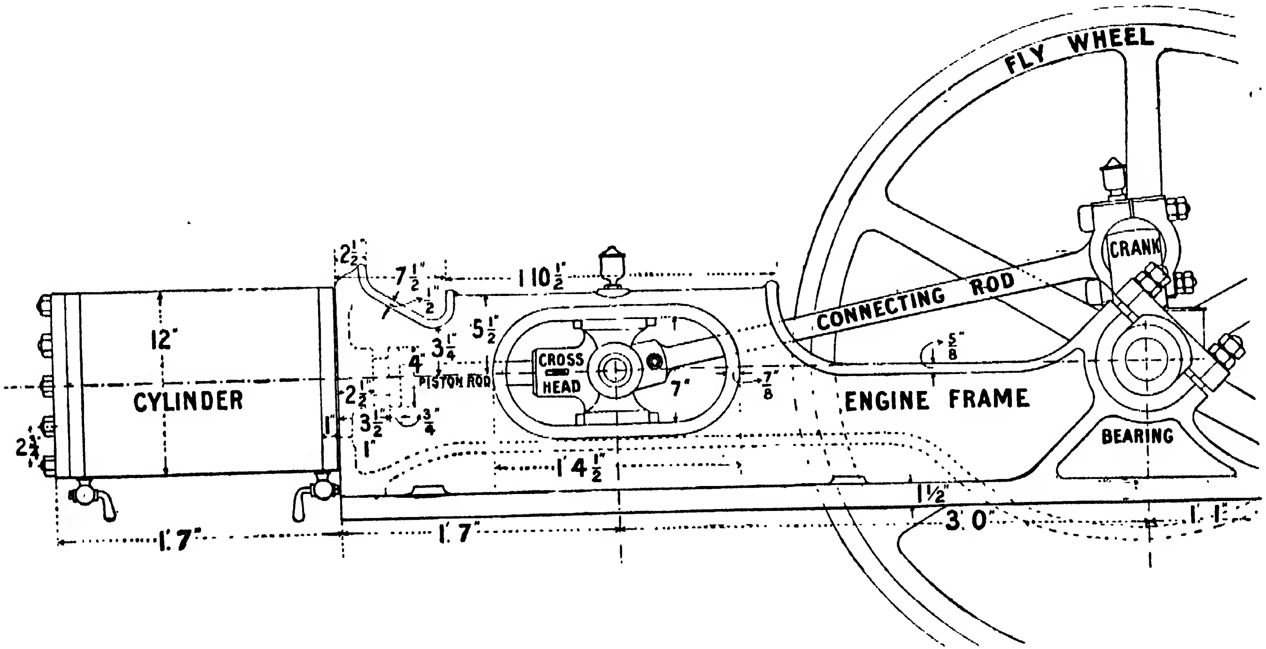


FIG. 172.—Horizontal Engine.

Example. Draw the elevation of the horizontal engine (Fig. 172). Some of the dimensions are given in the diagram. Details of the *connecting rod*, *connecting rod ends*, *crosshead*, *crank* and *crank shaft* bearing, are given in Figs. 202, 192, 144.

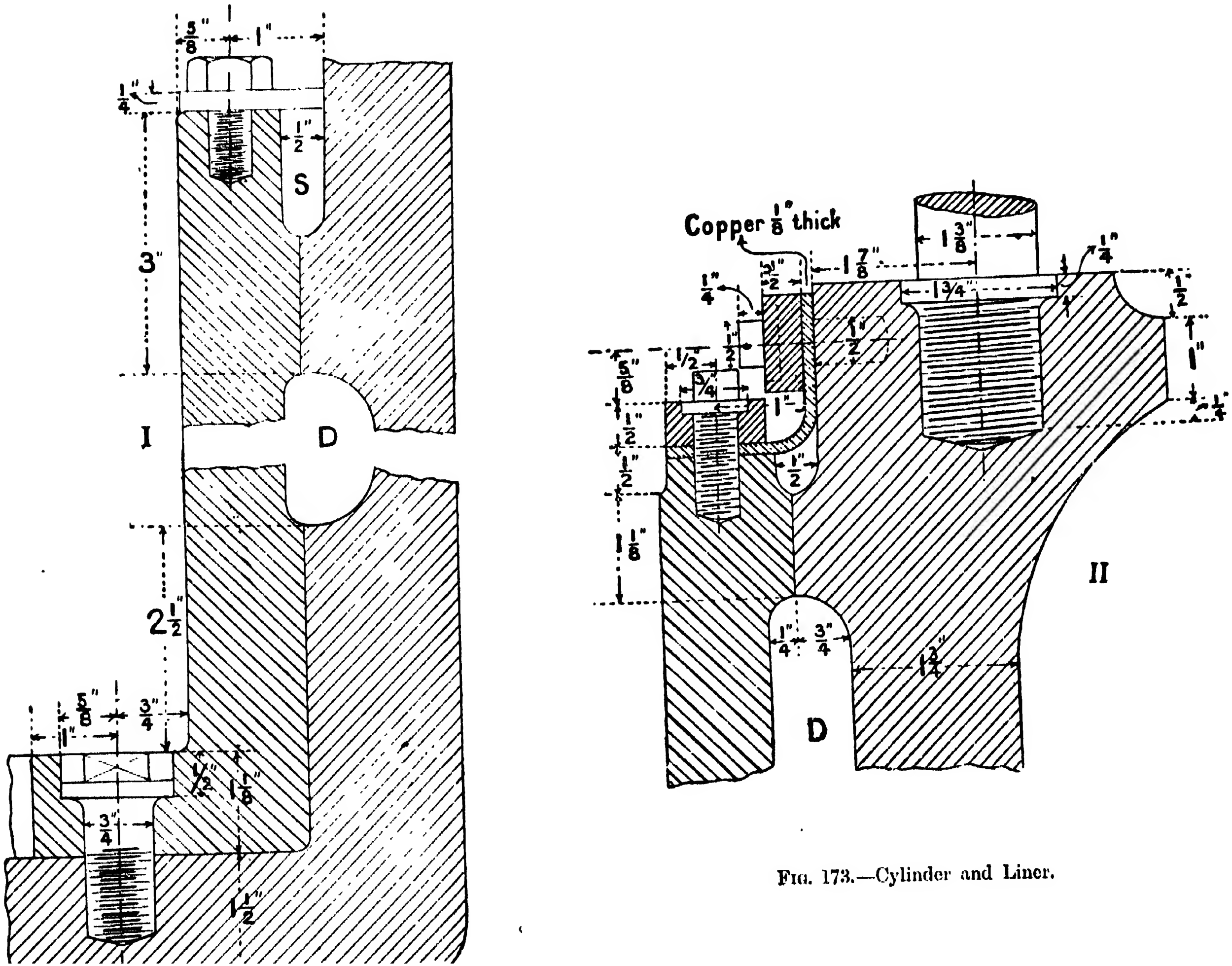


FIG. 173.—Cylinder and Liner.

Cylinders. The internal surface of a cylinder should present a hard and smooth surface. To ensure that this is the case, what is called a *liner* is frequently used, especially in cylinders of comparatively large size. Such liners have been made of steel, but hard close-grained cast iron is usually employed for the purpose. Arrangements have to be made not only to secure the liner to the cylinder, but also to allow for expansion. The liner may be secured to the cylinder by bolts passing through a flange, the heads of the bolts being recessed into the flange. The joint between the liner and the cylinder, at the end near to the cylinder cover, must be kept steam tight and must also allow for expansion. For such a purpose the arrangement adopted may be that shown at **I** or at **II** (Fig. 173).

In **I** a small stuffing box **S** is used, and this box when packed with asbestos or other suitable material makes a steam-tight joint. The lower part of the liner is flanged and secured to the cylinder by means of set screws with square heads.

In **II** a copper ring is used, and this is fastened to the liner and cylinder by set screws.

It will be noticed that the liner is made to fit the cylinder for a comparatively short distance at each end only, and this reduces the labour and expense in machining. The space **D** between the liner and the cylinder varies from $\frac{3}{4}''$ to $1\frac{1}{4}''$ in depth, and is usually kept filled with steam, thus acting as a steam jacket.

Example. Draw the sections of the liner and the cylinder shown in Fig. 173. Scale full size.

Pistons. A piston is usually cylindrical in form on account of the ease and accuracy with which a cylindrical cylinder can be produced by means of workshop tools. As already indicated, the piston moves forwards and backwards in a hollow cylinder, giving rotary motion to the crank shaft by means of the piston rod, crosshead, connecting rod, and crank. In this to and fro motion, whether the driving force be steam, gas, oil, or water-pressure, the arrangement must be such as to prevent leakage from one side of the piston to the other.

In the cylinder of a steam, gas, or oil engine, the leakage may be prevented by some suitable form of metallic packing.

In the cylinder of a hydraulic engine, in which water under comparatively great pressure is used, some form of leather packing is necessary. The packing is usually made in the form of a ring, or is cup-shaped in form (Fig. 178).

Ramsbottom's packing. One of the simplest forms of metallic packing, which is largely used for

locomotive pistons, is that known as *Ramsbottom's*. The piston is made slightly smaller than the bore of the cylinder, and two or more rectangular grooves are cut in its rim to receive metal rings of similar section, and made of brass, cast iron, or steel. The rings are made larger than the bore of the cylinder, and a small piece is cut out of the periphery. The rings can then be sprung into place.

In Fig. 174, two views of a locomotive piston and part of the piston rod are shown; the bore of the cylinder is 18″, the piston is made slightly smaller or, about $17\frac{15}{16}''$ diameter, the rings are turned to $18\frac{3}{4}''$ diameter, and when cut they are sprung into position.

Example. Draw the two views of a locomotive piston and piston rod (Fig. 174); diameter of piston 18″; diameter of piston-rod end $2\frac{1}{2}''$; six threads per inch. Taper of cotter 1 in 24. Scale 3″ to 1′.

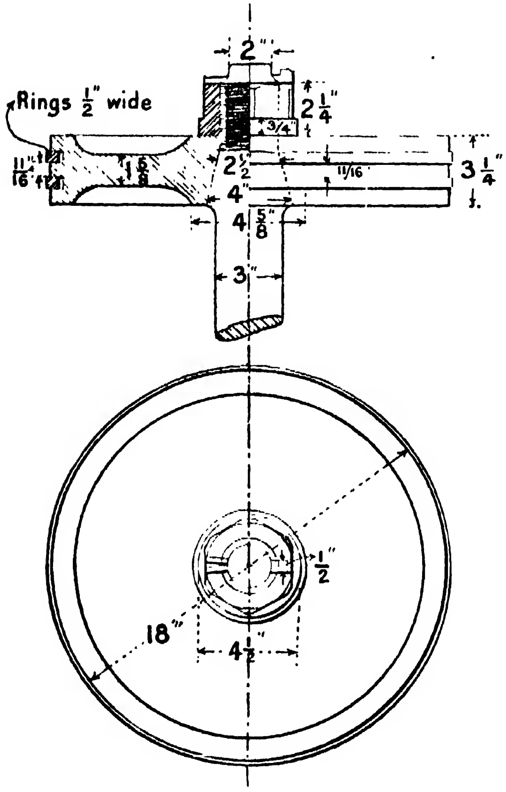


FIG. 174.—Locomotive Piston.

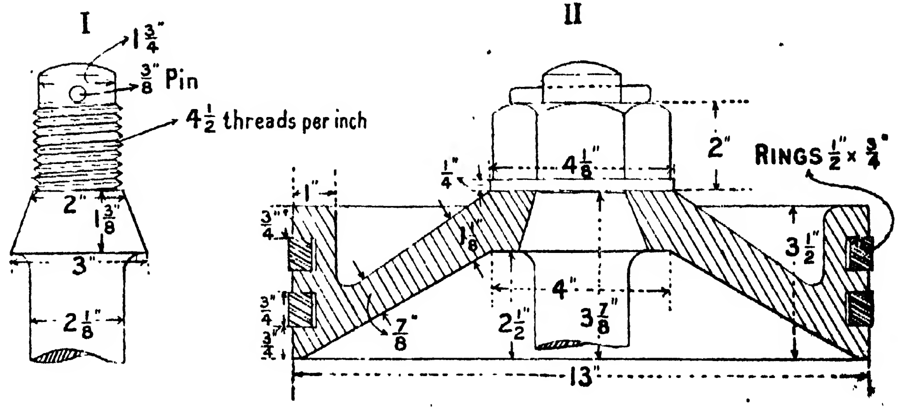


FIG. 175.—Locomotive Piston.

In the locomotive piston shown in Fig. 175, there are two cast-iron packing rings $\frac{3}{4}''$ wide in grooves $\frac{1}{2}''$ apart. The end of the piston rod, as indicated in the detail at **I**, is made in the form of a steep cone, and this expedient enables the piston to be removed readily when necessary.

Example. Draw the section of the locomotive piston (Fig. 175). Draw also a plan and an end view. Scale half size.

Steel piston. For many purposes, and especially in marine engines in which the cylinder is vertical, it is necessary not only that the piston shall be of sufficient strength, but also that its weight shall be reduced as much as possible. These ends are effected by making the piston of cast steel, and as this material is much stronger (p. 227), the piston may be made about one-third lighter than if made of cast iron. The piston, as in Fig. 176, is made in a conical form. This shape not only makes it easier to cast, but also gives strength and rigidity to it.

The taper of the piston rod in the boss of the piston is usually from 1 in 3 to 1 in 4. The packing rings are pressed out by means of suitable springs, so that the pressure against the surface of the cylinder is from 3 to 5 lbs. per sq. in. The split in the piston ring is cut in an oblique direction, so that the edges may not score or cut the surface of the cylinder. Leakage at the split is prevented by a brass tongue piece, which is fixed to one end of the ring by screws.

The packing rings are held in position by a ring called a *junk ring*; this may be fastened to the piston either by studs and nuts or by set screws. The screws or nuts may be prevented from slacking back by various locking arrangements. The usual method, as in Figs. 176, 177, is to use a *securing* or *guard ring*, which is made to bear against the flat faces of the heads or nuts, and is fastened to the piston by means of studs and nuts, the latter being secured by split pins as shown. The usual arrangement, when set screws or bolts are used, is to screw these into nuts or plugs of gun metal instead of into the metal of the piston. This plan avoids the danger of the bolts rusting and becoming set fast in place. The plugs, moreover, can be renewed easily when defective.

The bolt heads are sometimes sunk into the ring instead of standing above it. Instead of using a securing ring the "slacking-back" of the nuts may be prevented by using a split pin.

The nut at the end of the piston rod is secured by means of a locking plate, as in Fig. 177, secured by three or more small studs, the nuts being fixed by split pins.

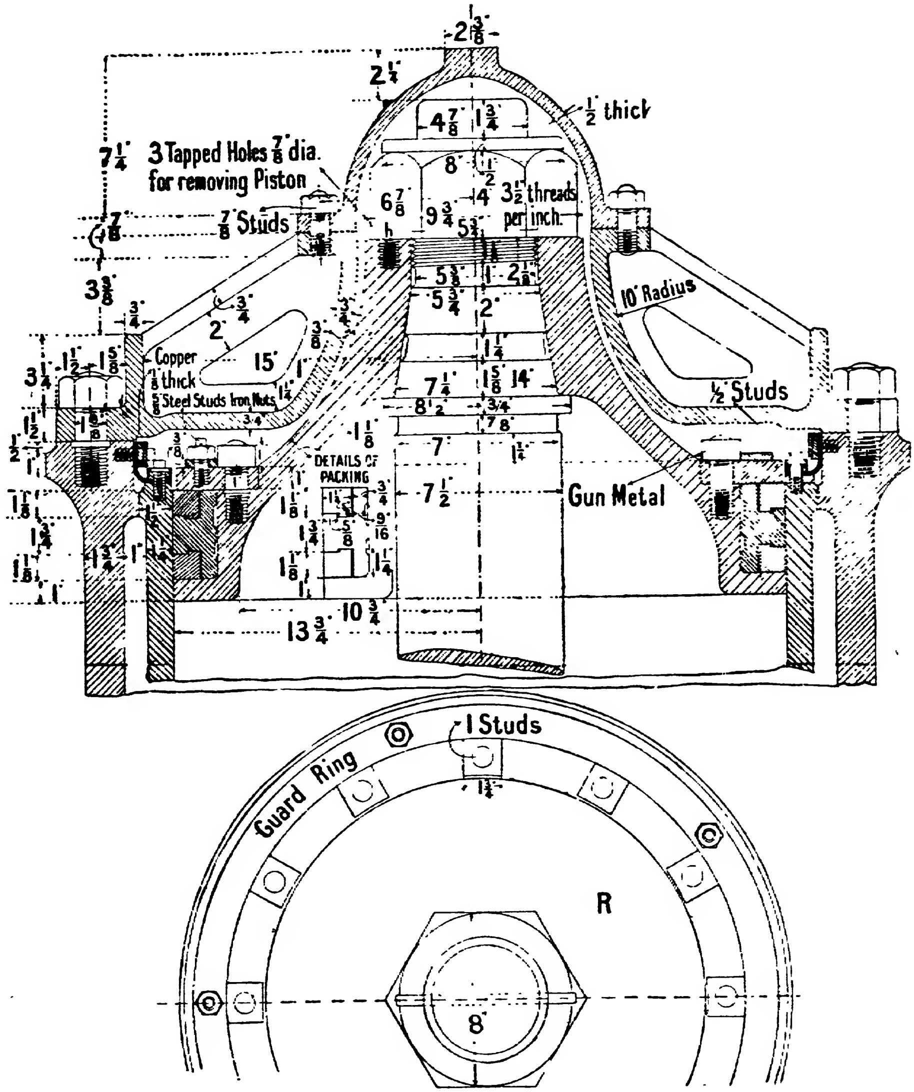


FIG. 176.—Steel Piston.

Example. Fig. 176 shows a section of a portion of the cylinder of a marine engine with a steel piston and rod. A portion of the plan is also shown. Draw a sectional elevation and complete the plan. Scale 3″ to 1′.

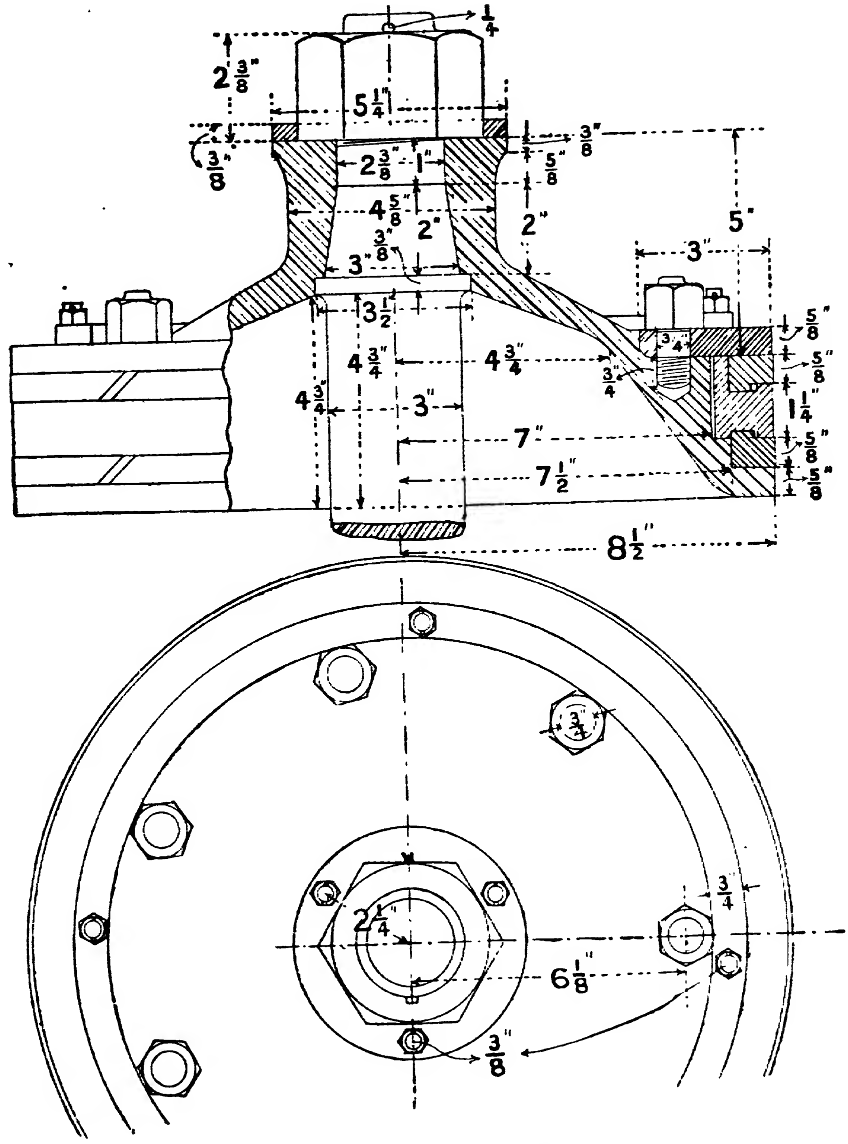


Fig. 177.—Forged Steel Piston.

Forged steel piston. Fig. 177 shows a sectional elevation and plan of a forged steel piston for a marine engine.

Example. Draw a sectional elevation and plan of the forged steel piston (Fig. 177). Scale half size.

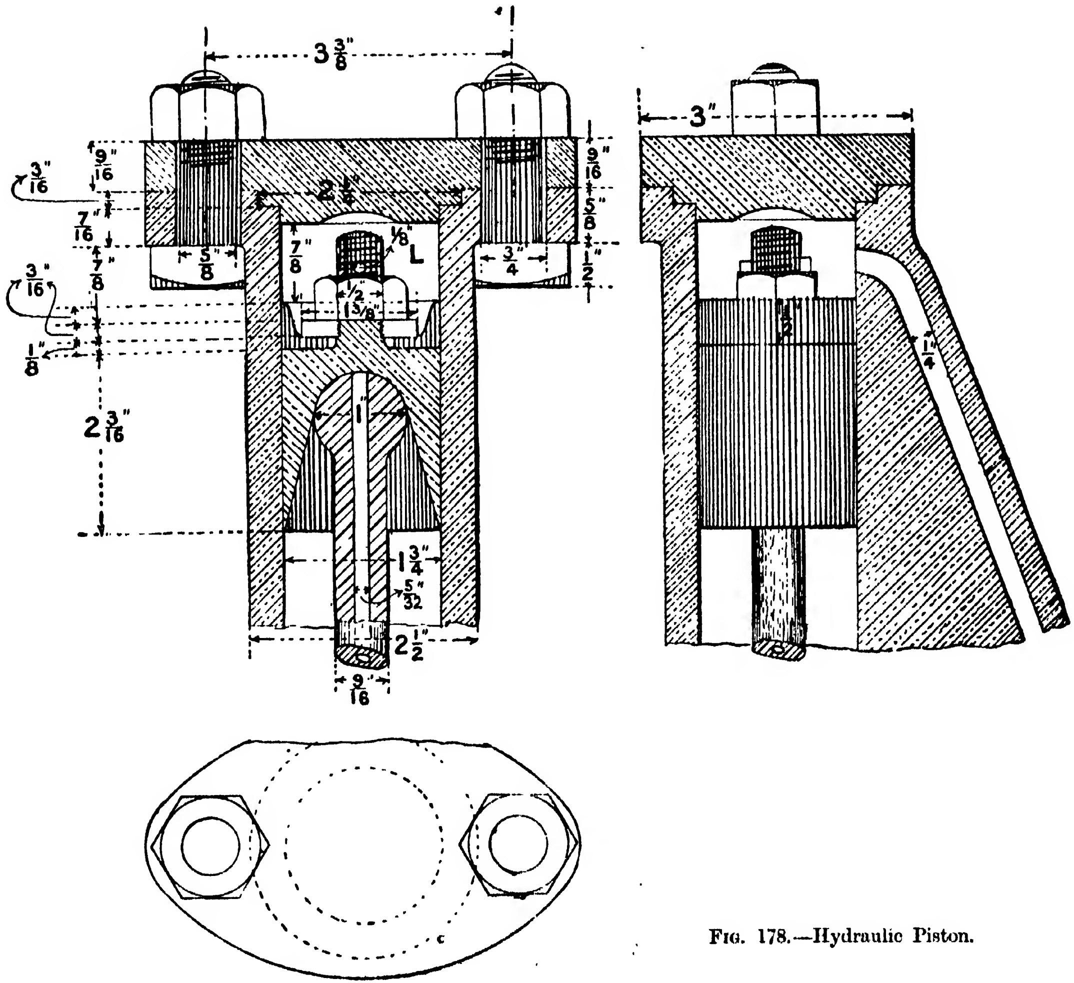


FIG. 178.—Hydraulic Piston.

Hydraulic piston. When water under pressure is used in the cylinder of an engine, the form of the piston is different from the preceding examples. One form is shown in Fig. 178. In this case the cylinder and piston are of brass, and the end of the steel piston rod in contact with the piston is made in a spherical form, for since the rod is throughout the stroke in a state of compression, it is not necessary to fasten the rod and piston together. The water-tight packing is furnished by a *hat leather* as shown. This leather is held in place by a washer and nut, while a small split pin prevents the slacking back of the nut.

In this form of hydraulic piston for what is known as a *single-acting* engine, the water pressure only acts on one side of the piston. The arrangement of the three pistons in an engine of this type is shown in Fig. 182.

A double leather packing is used when the water pressure acts alternately on each side of the piston. One form of piston adopted is shown in Fig. 181.

Example. Draw full size the three views of a single-acting hydraulic piston and cylinder (Fig. 178).

Water-pump bucket. Fig. 179 shows a piston or pump bucket with a hat-leather arrangement for preventing leakage. The water pressure acts alternately on each side of the flexible leather and is found to make a good joint for any pressure.

Example. Draw the two views of the hat-leather arrangement shown in Fig. 179 also draw an end view. Scale 6″ to 1′.

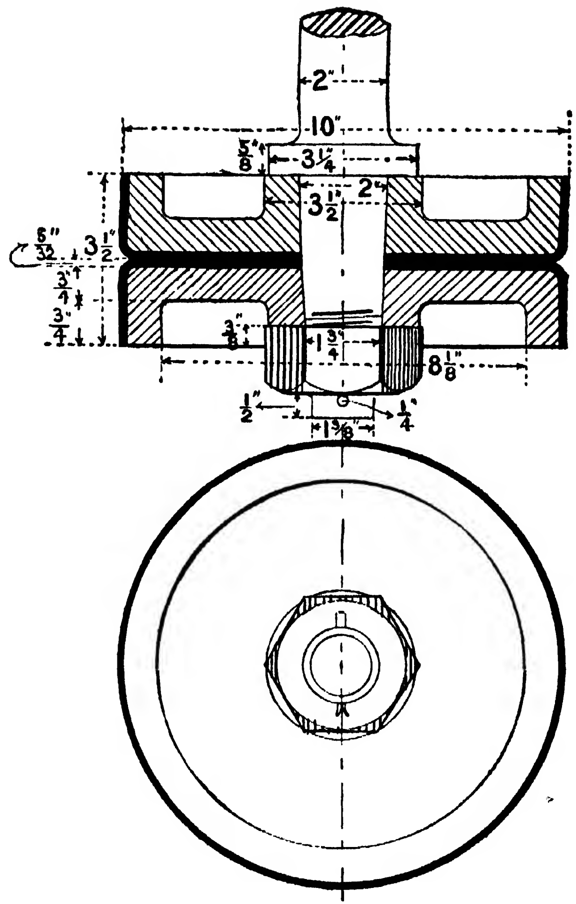


FIG. 179.—Water-pump Bucket.

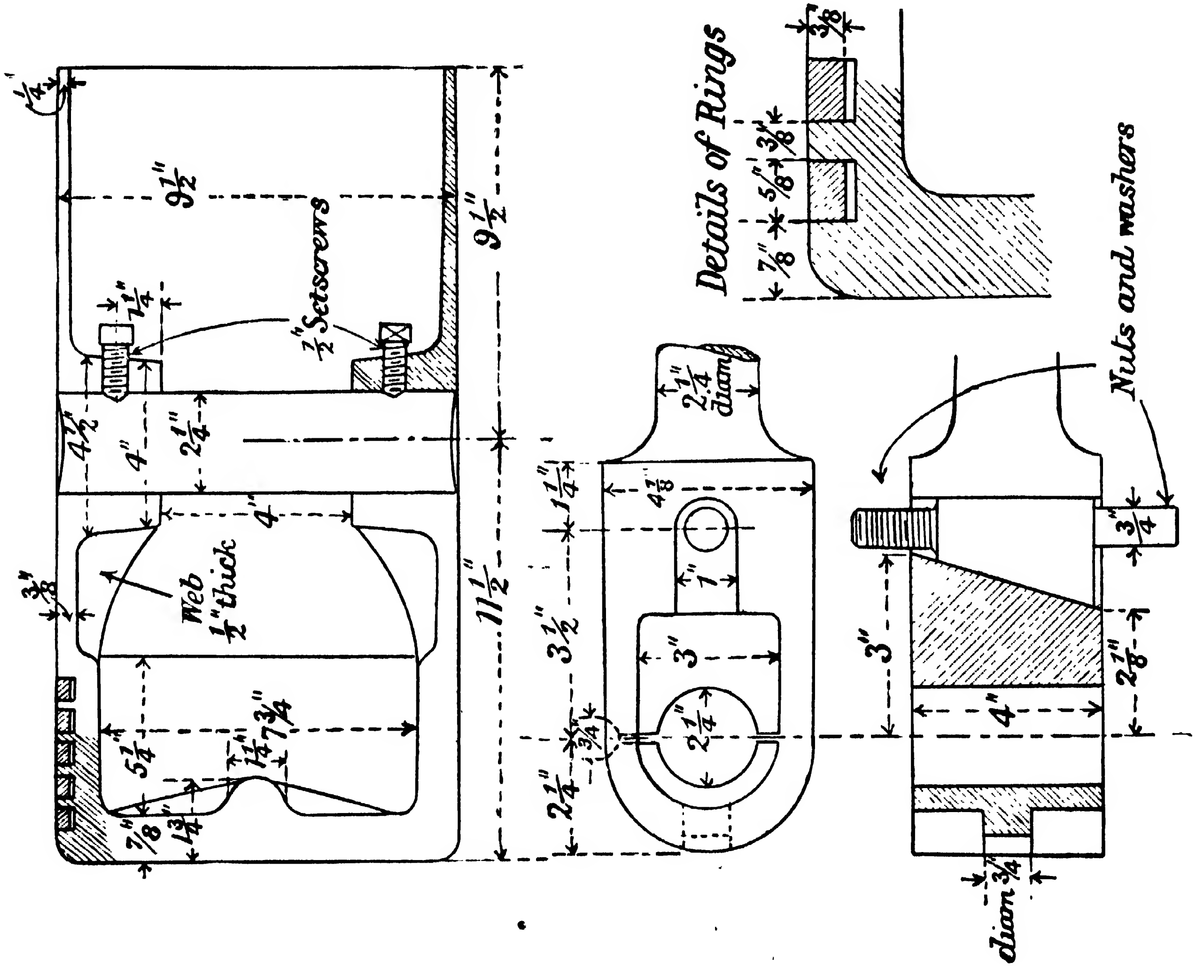


FIG. 180.—Piston and Connecting Rod End for Gas Engine.

EXERCISES. IX.

1. Explain how piston rings are made so that the piston may work steam-tight in the cylinder. How are these rings put into place?

2. Explain, by means of a sketch, the manner in which a piston rod is made to move so that the axis of the rod coincides with the axis of the cylinder.

3. Show, by sketches, the construction of a hydraulic piston suitable for high pressures. [B.E.]

4. Sketch and explain how a ram is made to work water-tight in the cylinder cover of a hydraulic press.

5. Sketch and describe one form of piston suitable for a steam engine and one suitable for a hydraulic engine. State the reasons for the difference in construction in the two cases, and also state in each case the materials used in the construction of the piston.

6. Give sketches showing two or more methods of fastening the piston rod to the piston of an engine.

7. State the essential points to be secured in the design of a piston for a steam engine. Illustrate your answer by sketching any good form of piston.

8. Explain the advantages of providing a separate piece for the liner of a steam-cylinder. With the aid of sketches describe how the liner is fitted at each end of the cylinder.

9. Fig. 180 shows the piston with connecting rod end for a gas engine. Draw half size three views in which the parts are properly connected together. (i) A side elevation in which the upper half is to show a section taken through the axis of the cylinder, and lower half an outside view of the piston. (ii) A sectional plan taken through the axis of the piston. (iii) An end elevation looking into the open end of the piston. [B.E.]

10. The diagram (Fig. 181) shows a piston and plunger for hydraulic pressure. Draw the parts connected together, the covers to be secured by studs and nuts. Draw a sectional elevation, also a view of the end, **L**; the right half with the cover removed, and the left half with the cover in place. Scale half size. [**B.E.**]

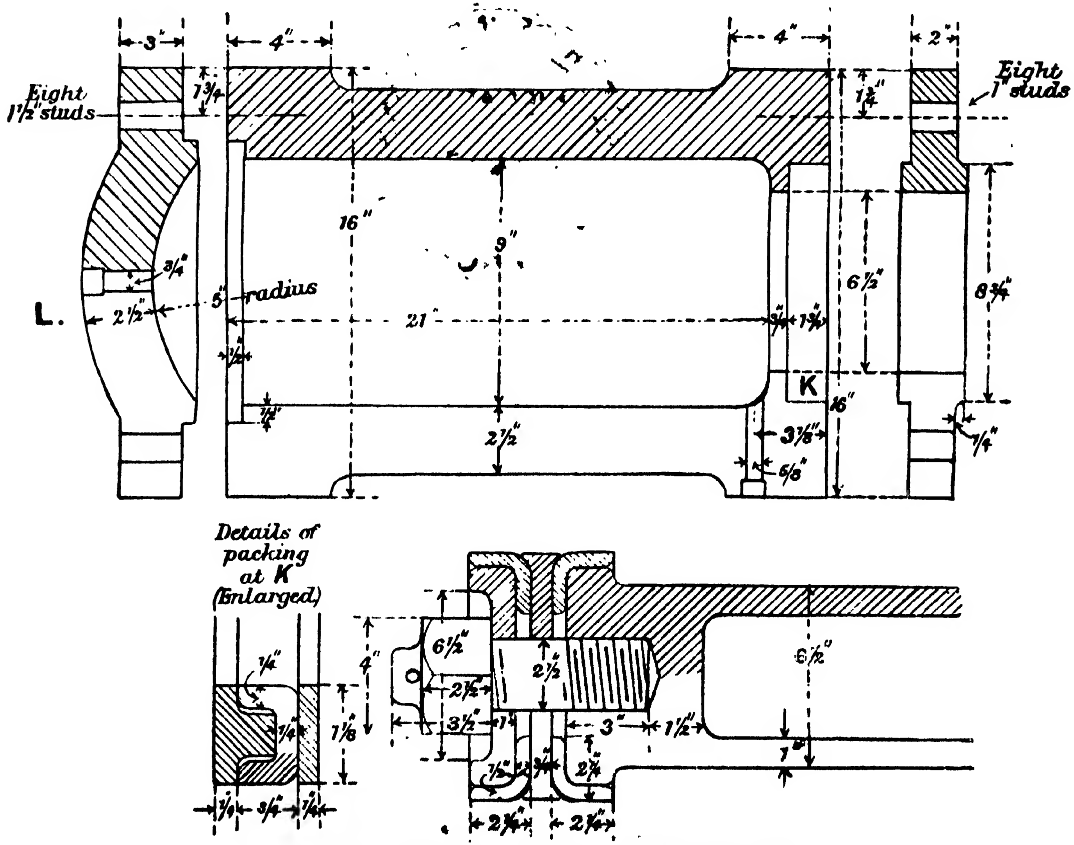


FIG. 181.—Piston and Plunger for Hydraulic Pressure.

11. Draw the two views shown of the three-cylinder Hydraulic Engine (Fig. 182). The water pressure is 700 lbs. per sq. in. Find the size of the two bolts for the cover, and show the bolts in both views. Scale half size. [B.E.]

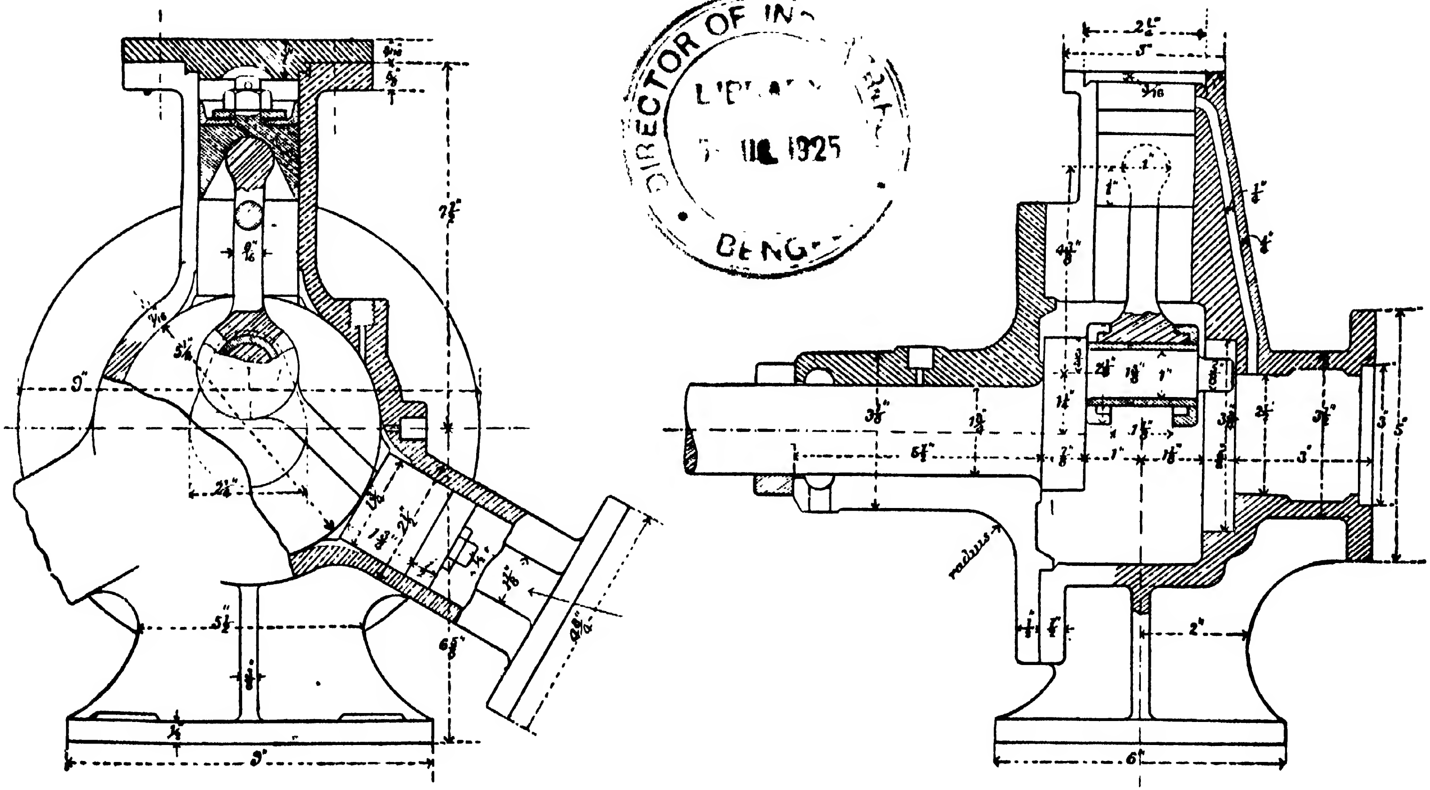


FIG. 182.—Three Cylinder Hydraulic Engine.

CHAPTER X.

STUFFING BOXES AND GLANDS

Gland and stuffing box. The piston rod of a steam, gas, or other engine must slide freely through the cylinder cover of the engine, and there must be no leakage past the rod during its to and fro motion. Such leakage is prevented by using a *stuffing box*, which consists of a hollow cylindrical box in which asbestos or other suitable material is placed. The stuffing box also acts as a guide for the rod, ensuring that the axis of the rod always coincides with the axis of the cylinder. The friction between the rod and the stuffing box is lessened by using a suitable alloy for the rubbing surfaces.

Fig. 183 shows a simple form of stuffing box, which consists of a cylindrical box, **S**, on the outside of which a screw thread is formed; a gland, **G**, is made to fit the box and can be forced downwards by means of a hexagonal nut, **N**. The lower part of the stuffing box is bored to fit the rod. Asbestos or other suitable packing inserted in the space **P** is compressed and forced tightly against the rod by rotating the nut **N**.

Example. Draw the two views of the stuffing box and gland (Fig. 183). Draw also an end view. Scale full size.

In the form just described, all the parts—the box, gland, etc.—are of brass, and this is usually the case when it is of comparatively small size. In larger sizes, the box and gland are made of cast iron and the rubbing surfaces are provided by brass bushes inserted in the gland and in the lower part of the stuffing box.

In Fig. 184 a gland and stuffing box for a vertical engine are shown. The stuffing box **S** and gland **G** are of cast iron; a brass bush which tightly fits the gland and another bush inserted at the bottom of the stuffing box, form the rubbing surfaces.

A steam-tight joint is obtained by suitable packing placed in the space **P** and forced against the sides of the piston rod by means of the three studs shown.

Example. Draw to a scale 6″ to 1′ the two views shown of a stuffing box and gland, also draw an end view.

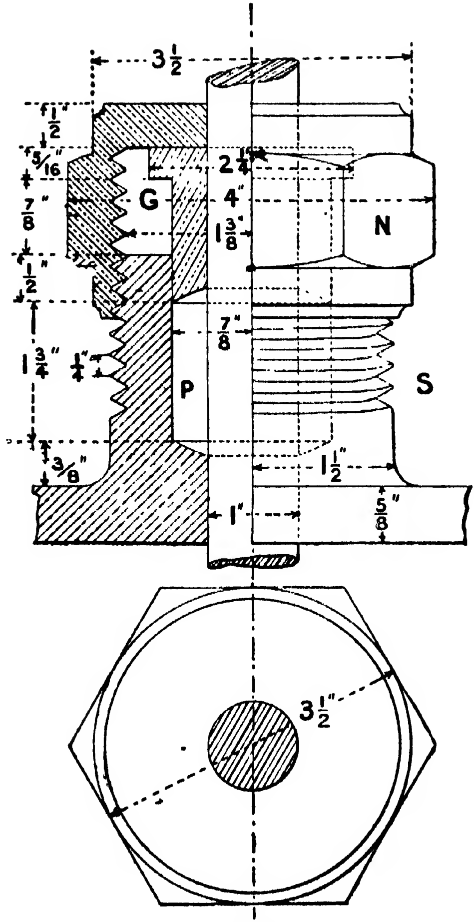


Fig. 183.—Stuffing Box.

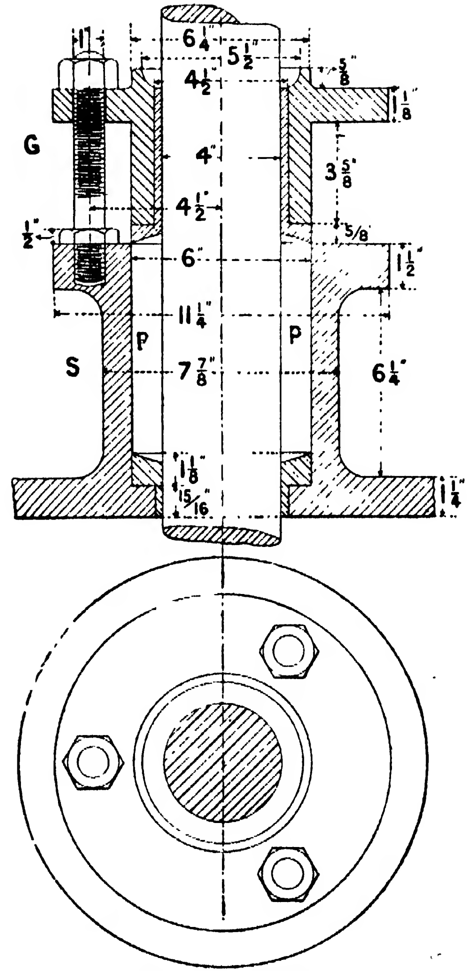
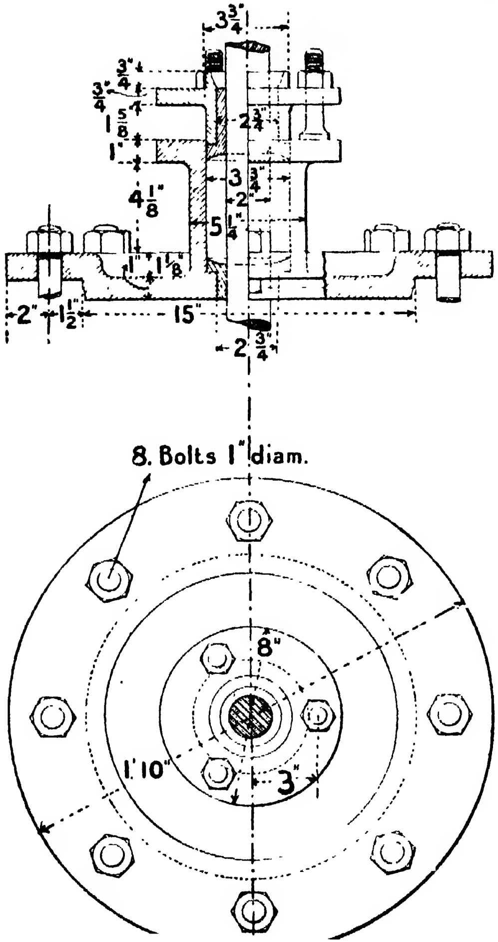


Fig. 184.—Stuffing Box and Gland.



Example. In Fig. 185 two views of a stuffing box, gland, and cylinder cover are shown. Draw to a scale 4″ to 1′. Also add an end view.

Packing. The material used for packing depends not only on the pressure of the fluid but also on its temperature. *Hemp* or some form of india-rubber packing is used for comparatively moderate steam or water pressure; but such packing is not suitable for steam of high pressure, and consequent high temperature. Asbestos fibre has been much used for this purpose, though it is found to be unsatisfactory when exposed to heavy and continuous friction, such as in the stuffing box for a piston rod. Some form of *metallic packing* is found not only to work with less friction but to be less liable also to score the rod than asbestos or other kind of packing. Metallic packing is made in a variety of forms and may consist of a series of white metal rings alternating with similar rings of gun metal. The rings are made of triangular section as shown in Fig. 186, and as the gland is forced in, the white metal rings are by the action of the inclined surfaces pressed against the surface of the rod.

During the process of screwing down the gland, a number of spiral springs—usually enclosed in or carried by a frame at the bottom of the stuffing box (as shown at S, Fig. 186)—are compressed. In this manner the pressure upon the rod is maintained, during a slight amount of wear, by the elasticity of the springs.

The nuts on the stuffing box require to be rotated simultaneously. To effect this one plan is to use nuts made in the form of toothed pinions. These pinions are all connected together by a toothed ring held to the face of the gland by suitable clips. The pitch circles of the ring and the pinions are indicated by dotted circles in the plan (Fig. 185). Motion is given to the ring and the pinions by means of a suitable worm rotating in bearings as indicated.

Example. Draw, to scale 6″ to 1′, the stuffing box and gland for the piston rod of a vertical engine.

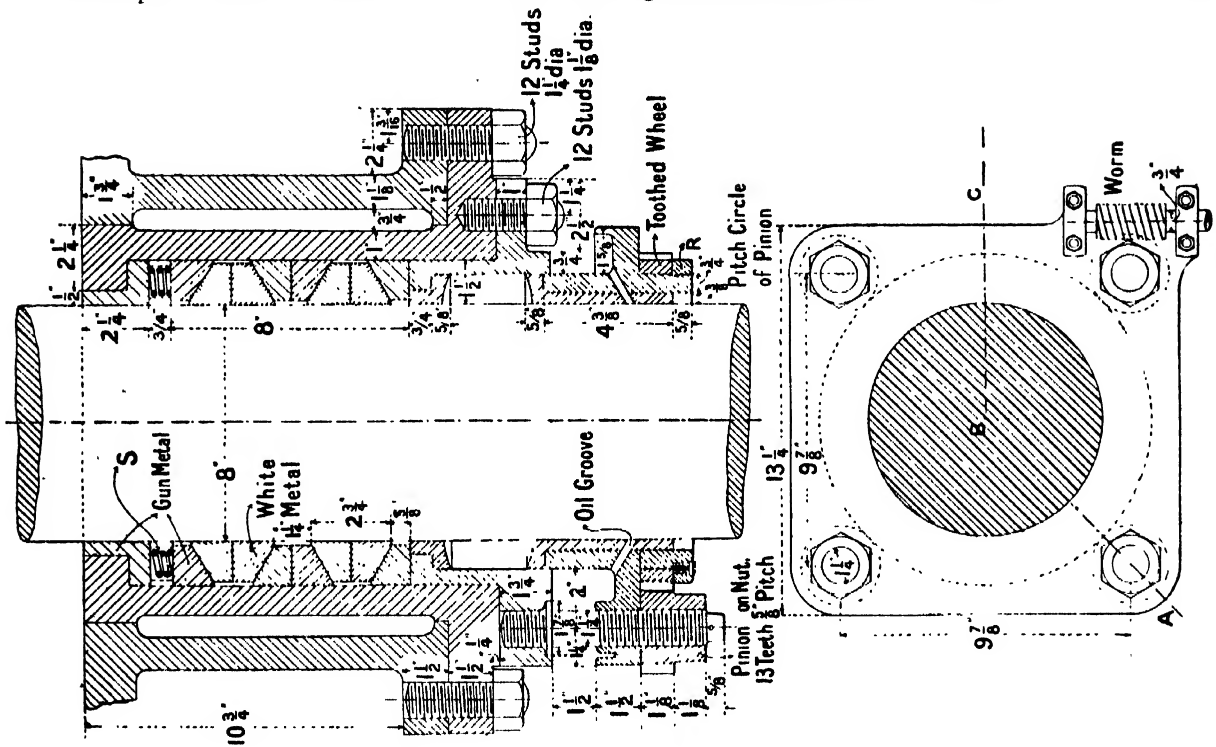


FIG. 186.—Metallic Packing.

Hydraulic packing. Leather packing—in the forms known as *cup-leather* or *hat-leather*—is used. The packing consists of a leather washer moulded into the form of an annular ring (Fig. 188). The ring may be placed in a recess or chamber formed in the side of the cylinder. When in action the fluid under pressure leaks past the ram, R, into the chamber C, and acting on the inside of the joint forces the leather tightly against the sides of the ram, thus ensuring a tight joint. The tightness of the joint

increases with the increase in the pressure. Some difficulty may be experienced in the form shown in Fig. 187 in placing the leather in position; this difficulty may be avoided, however, by using the form of gland in Fig. 188.

Double cup-leather. In the case of the piston of a hydraulic engine, there may be great pressure on one side of the piston or on both sides. In the former case, a single cup-leather, as in the piston of the Brotherhood engine (Fig. 182), may be used, and in the latter a double cup-leather would be required (Fig. 181).

EXERCISES. X.

1. Describe how a steam-tight joint is made between the cylinder and the cylinder cover of a steam engine. Show how a piston rod is enabled to work steam-tight through a cylinder end or cover. What alternative plan could be adopted when water is the pressure fluid used instead of steam?

2. Sketch in section a stuffing box and gland, with bolts or studs, in the construction of which cast iron, wrought iron, and brass are employed. Explain why these different materials are used for the various parts. [B.E.]

3. Draw a section of a simple form of stuffing box suitable for a valve rod, so made that neither studs nor bolts are required for tightening the gland.

4. What is packing? Name the principal materials of which it is made. What kind is generally used in a stuffing box to prevent leakage of steam? Sketch two methods of tightening glands when the packing becomes worn.

5. Show, by sketches, how cup-leather packing is used to prevent leakage of water in hydraulic presses.

6. Describe how the lubrication is provided for in the stuffing box and the cylinder of an engine.

7. Describe an arrangement for screwing up imultaneously the several nuts of the gland of a large stuffing box. [B.E.]

8. Explain, with sketches, one form of metallic gland packing for the piston rod of a steam engine. State the advantages due to the use of metallic packing as compared with other material.

9. A stuffing box and gland are shown in Fig. 189. Draw the two views shown, and also draw an end view. Scale half size. [B.E.]

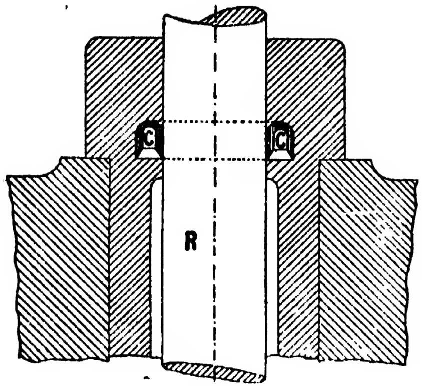


Fig. 187.—Hydraulic Packing.

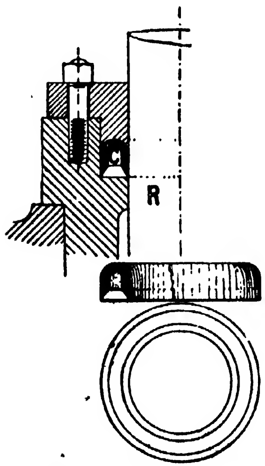
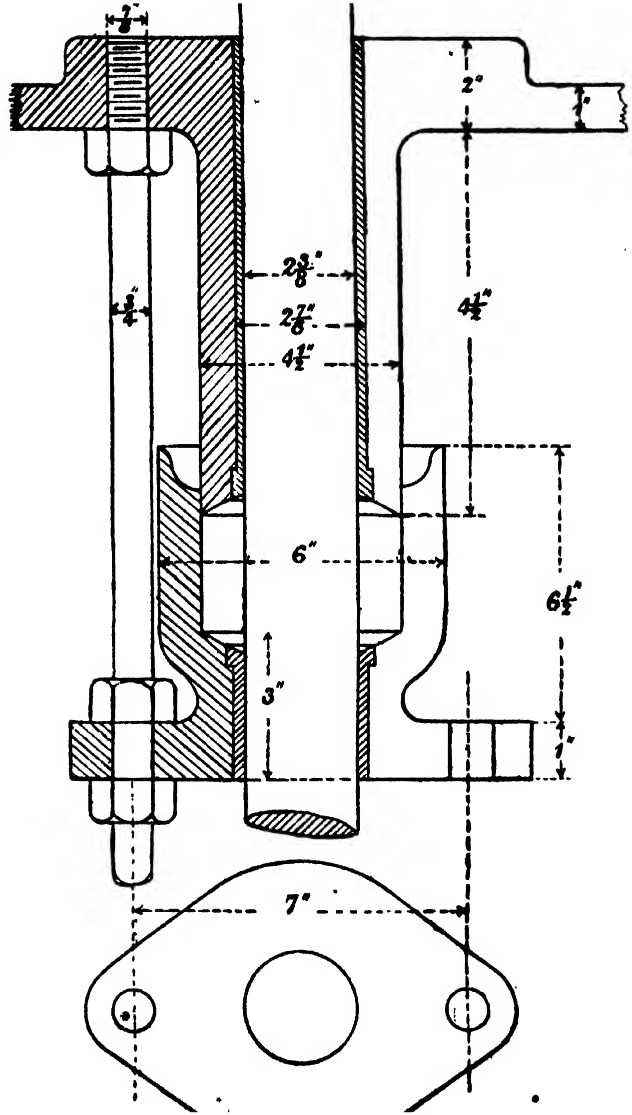


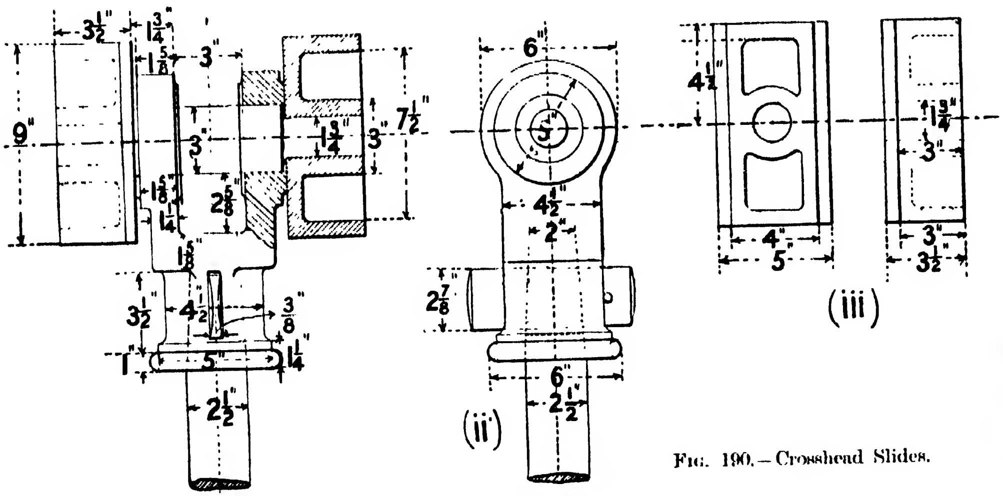
Fig. 188.—Cup Leather Packing.



CHAPTER XI.

CROSSHEADS AND SLIDE BARS.

Crosshead and slides. The connection between a piston rod and a connecting rod may be made by means of a crosshead. One form of crosshead is shown in Fig. 190.



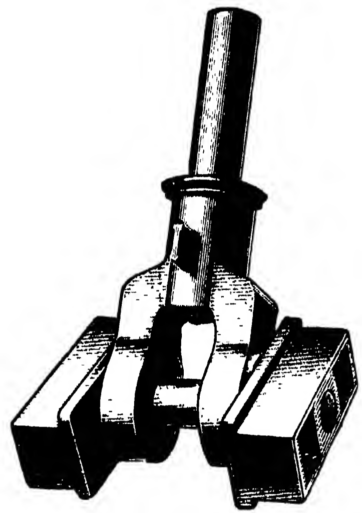


FIG. 190.—Crosshead Slides.

Detailed drawings of the end of the piston rod and slides are given at (ii) and (iii). From the former, it will be seen that the end of the rod is made of a taper form, and is secured to the crosshead by a cotter.

The dimensions and general form of the crosshead and slides may be seen from the diagram.

Example. Draw the details of the crosshead and slide bars (Fig. 190). Scale half size.

Guide bars. The two slides (Fig. 190) move backwards and forwards, the centre of the crosshead moving in a horizontal line. This motion is ensured by means of guide bars, a pair of which are indicated in Fig. 191.

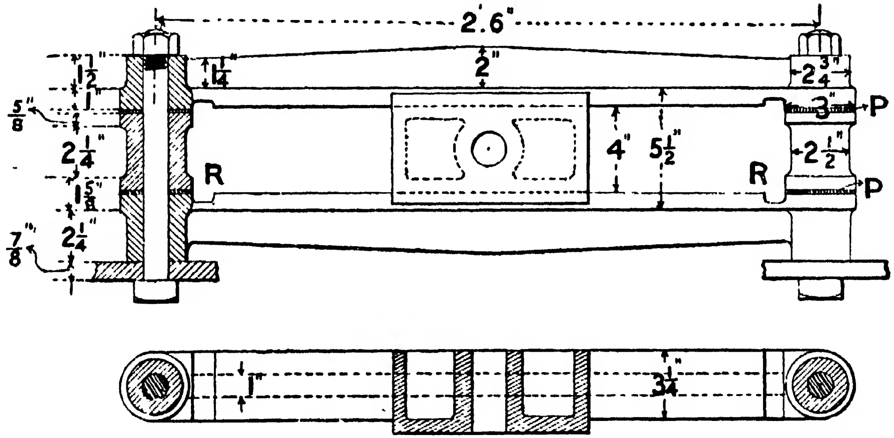


FIG. 191.—Guide Bars.

It will be noticed that small recesses, **R**, **R**, are made at each end of the guide bars. The edges of the slides entering these recesses during each to and fro motion of the crosshead prevents the formation of a ridge, which would otherwise occur owing to the wear of the slides.

Adjustment for wear may be made by means of *distance pieces*, **PP**, which are inserted as shown at the ends of the guide bars.

Example. Draw the two views of the guide bars shown in Fig. 191. Also insert in their proper positions the crosshead and slides of Fig. 190.

Crosshead. Fig. 192 shows an arrangement in which the guides for the crosshead consist of two arcs of circles, the axis being coincident with the axis of the cylinder. Compensation for wear may be made by means of the two wedge-shaped bolts.

Example. Draw, half size, the two views of a crosshead (Fig. 192). Also draw a plan.

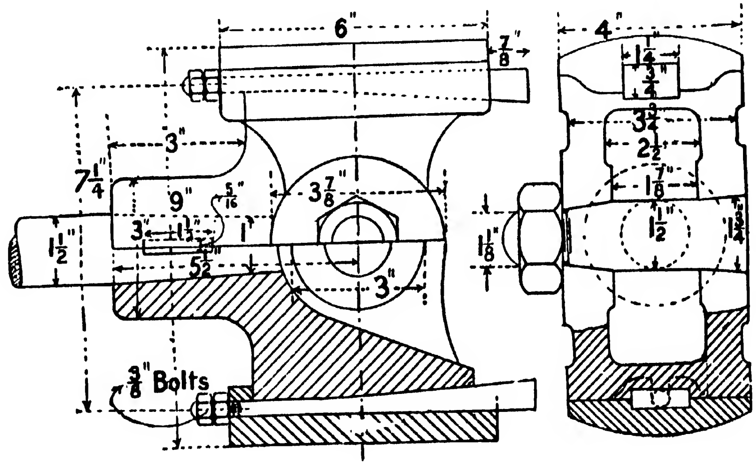


FIG. 192.—Crosshead.

In some cases the rod and crosshead are forged in one piece, and afterwards machined to the requisite size and form. Fig. 193 shows such an arrangement.

Example. Draw, half size, the two views of the crosshead (Fig. 193).

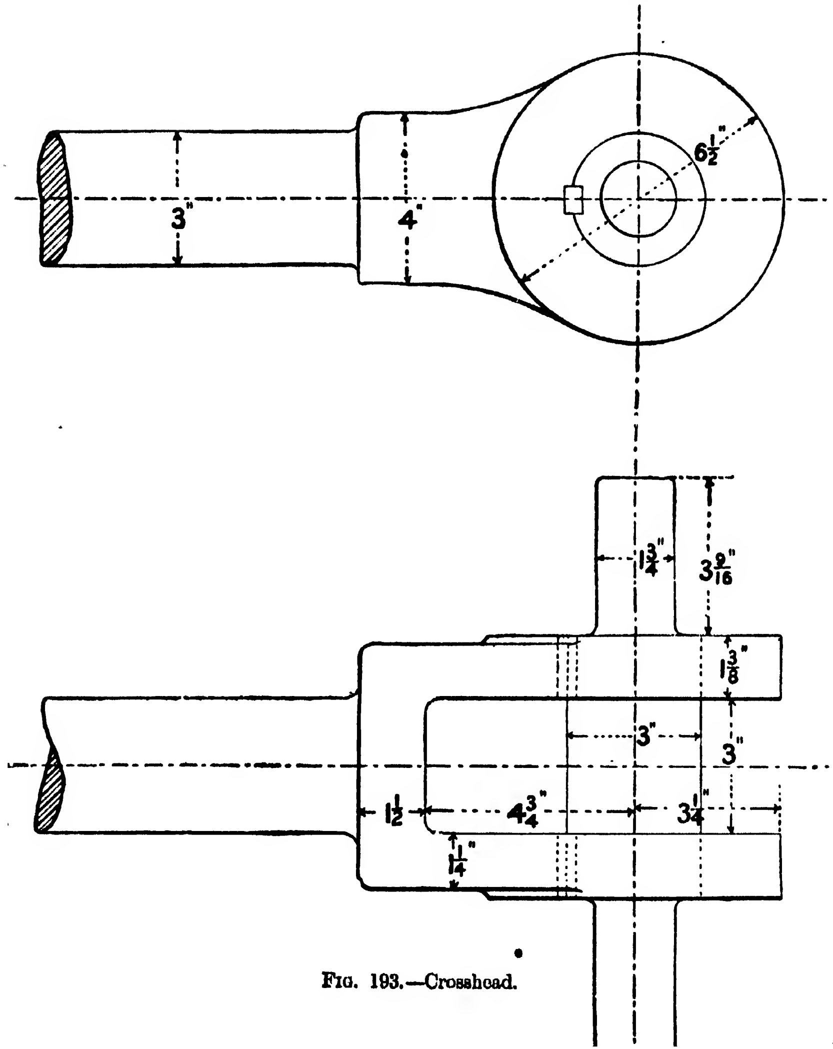


FIG. 193.—Crosshead.

Forged steel crosshead for marine engine. Fig. 194 shows a form of crosshead suitable for a marine engine. The rubbing surfaces are of white metal, which is placed in suitable grooves and hammered in.

Example. Draw the two views of crosshead (Fig. 194). Scale half size. Also draw a plan.

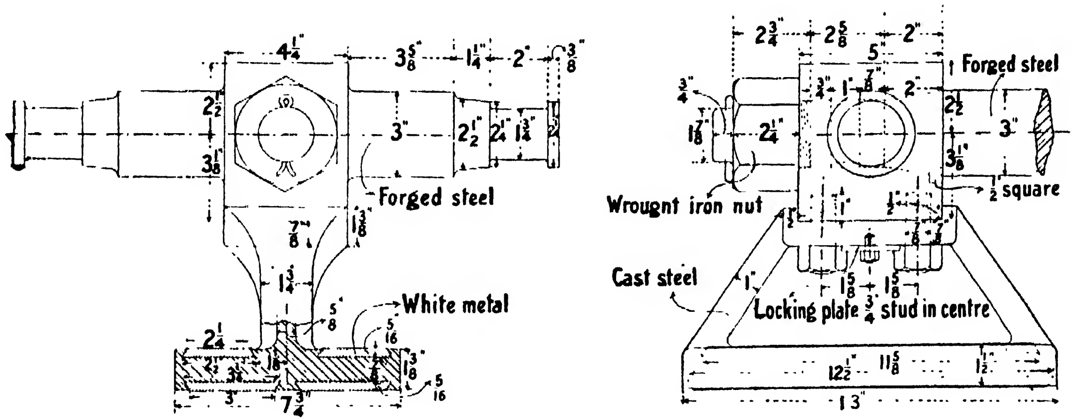
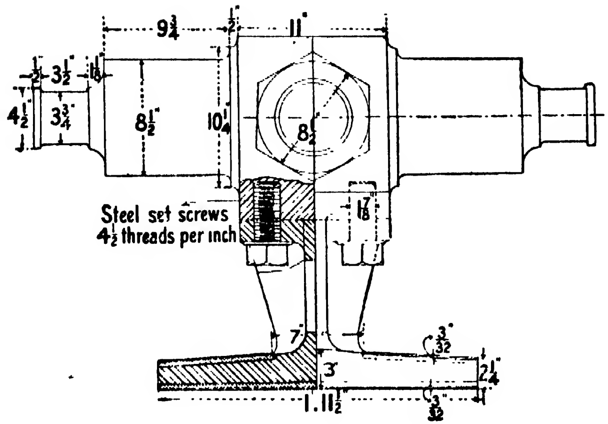
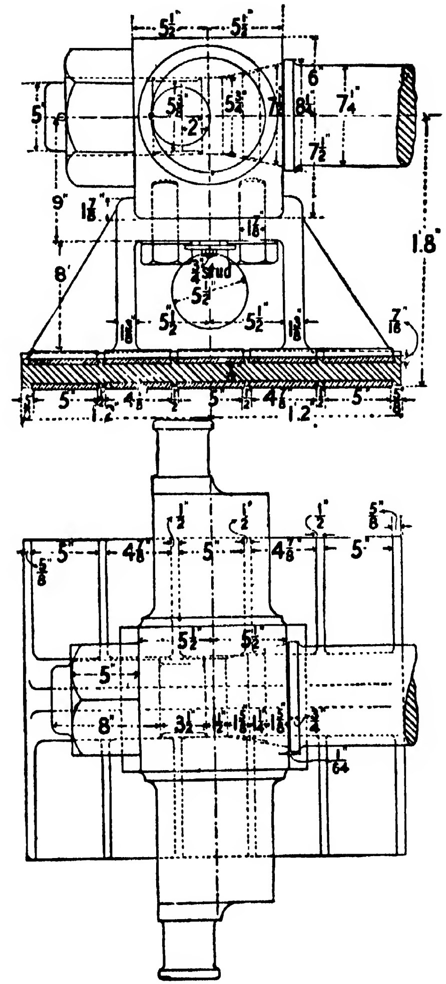


FIG. 194.—Forged Steel Crosshead.

Some of the remaining forms of crossheads and guide blocks used are shown in Figs. 196-200. Thus in Fig. 197 adjustment for wear can be made by means of the set screw shown; the end of the screw is made to press against a steel plate. In Fig. 199 two views of a crosshead and slide block forged at the end of a piston rod are shown.





Another form of steel crosshead for a marine engine is shown in Fig. 195.

Example. Draw the three views of the crosshead (Fig. 195). Scale half size

FIG. 195.

EXERCISES. XI.

1. Make a sketch showing how a crosshead is secured to a piston rod by a cotter.
2. Draw the two views of the piston rod end (Fig. 196), and also draw a plan. Scale full size.

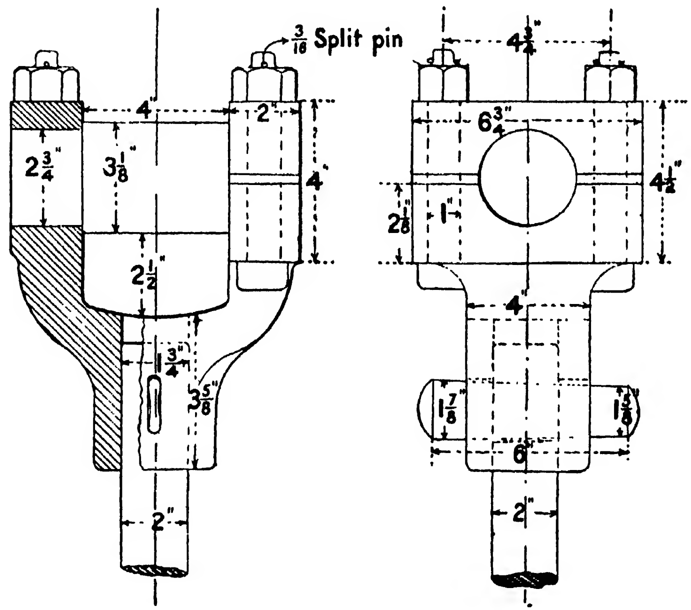


FIG. 196.

3. Fig. 197 shows a piston rod end and guide block of an engine. Draw full size a sectional elevation, a plan, and an end view, looking in the direction of the arrow. [B.E.]

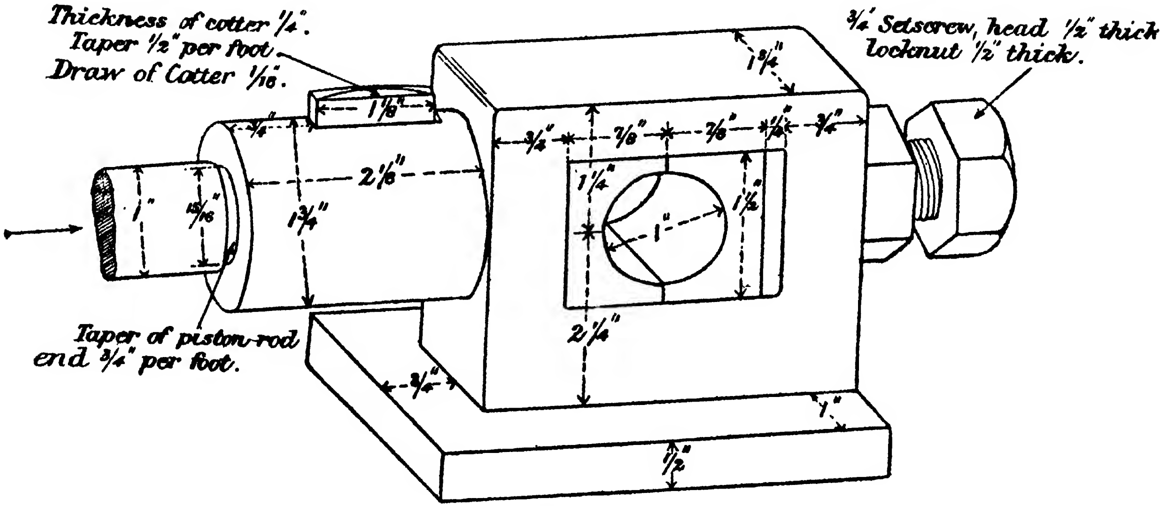


Fig. 197.

4. Complete the two views of the crosshead (Fig. 198). Also draw a plan. Scale half size.

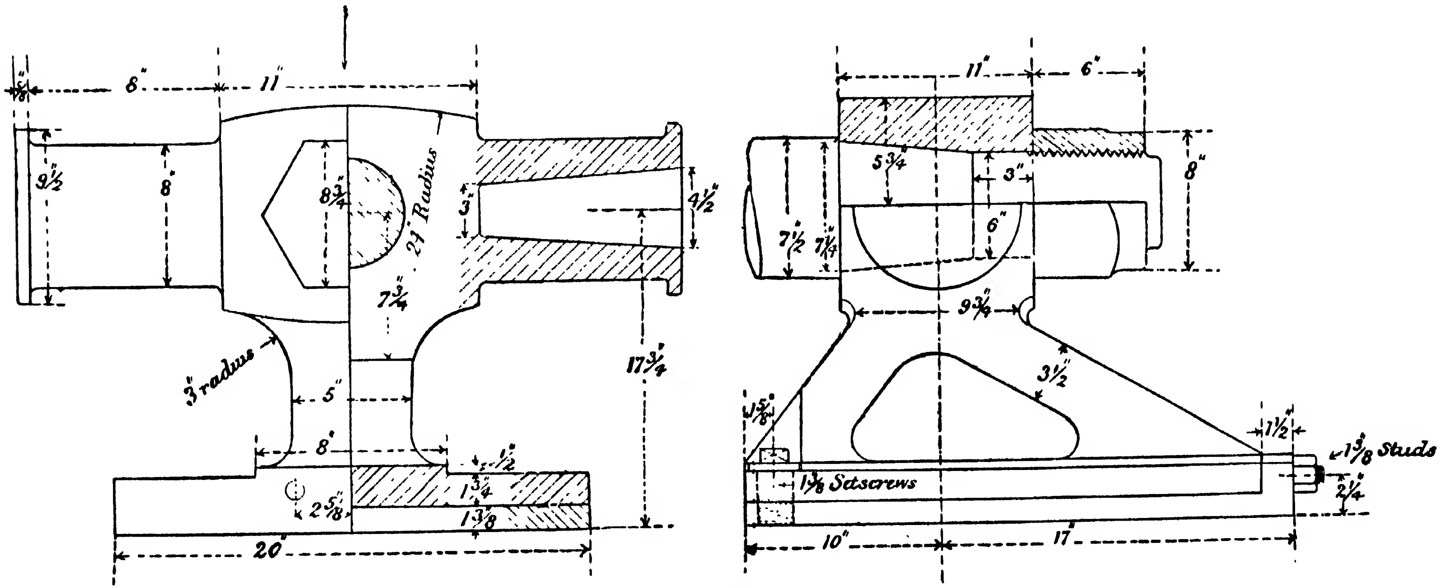


FIG. 198.

5. The diagram (Fig. 199) shows two views of a crosshead and slide block forged at the end of a piston rod. Draw these views and add a plan and a sectional elevation on the line **AB**. Scale full size.

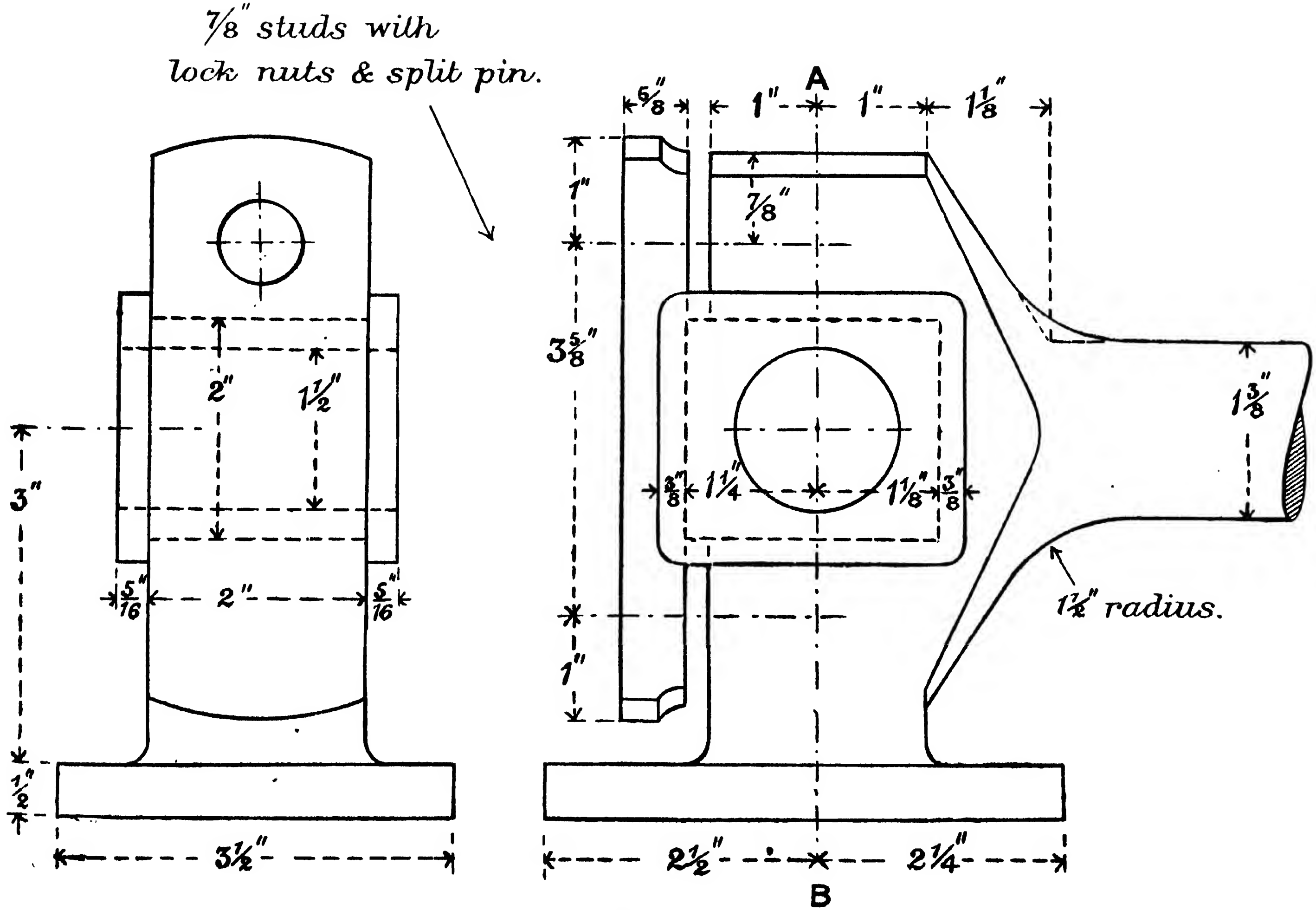

7/8" studs with
lock nuts & split pin.
A
5/8"
1"
1"
1 1/8"
1"
7/8"
3 5/8"
2"
1 1/2"
3"
3/8"
1 1/4
1 1/8"
3/8"
1 3/8"
5/16"
2"
5/16"
1 1/2" radius.
1"
1/2"
3 1/2"
2 1/2"
2 1/4"
B

FIG. 199.

6. Fig. 200 shows a sectional elevation of a crosshead and a portion of the piston rod. Draw half size. Add a plan and an end view. [B.E.]

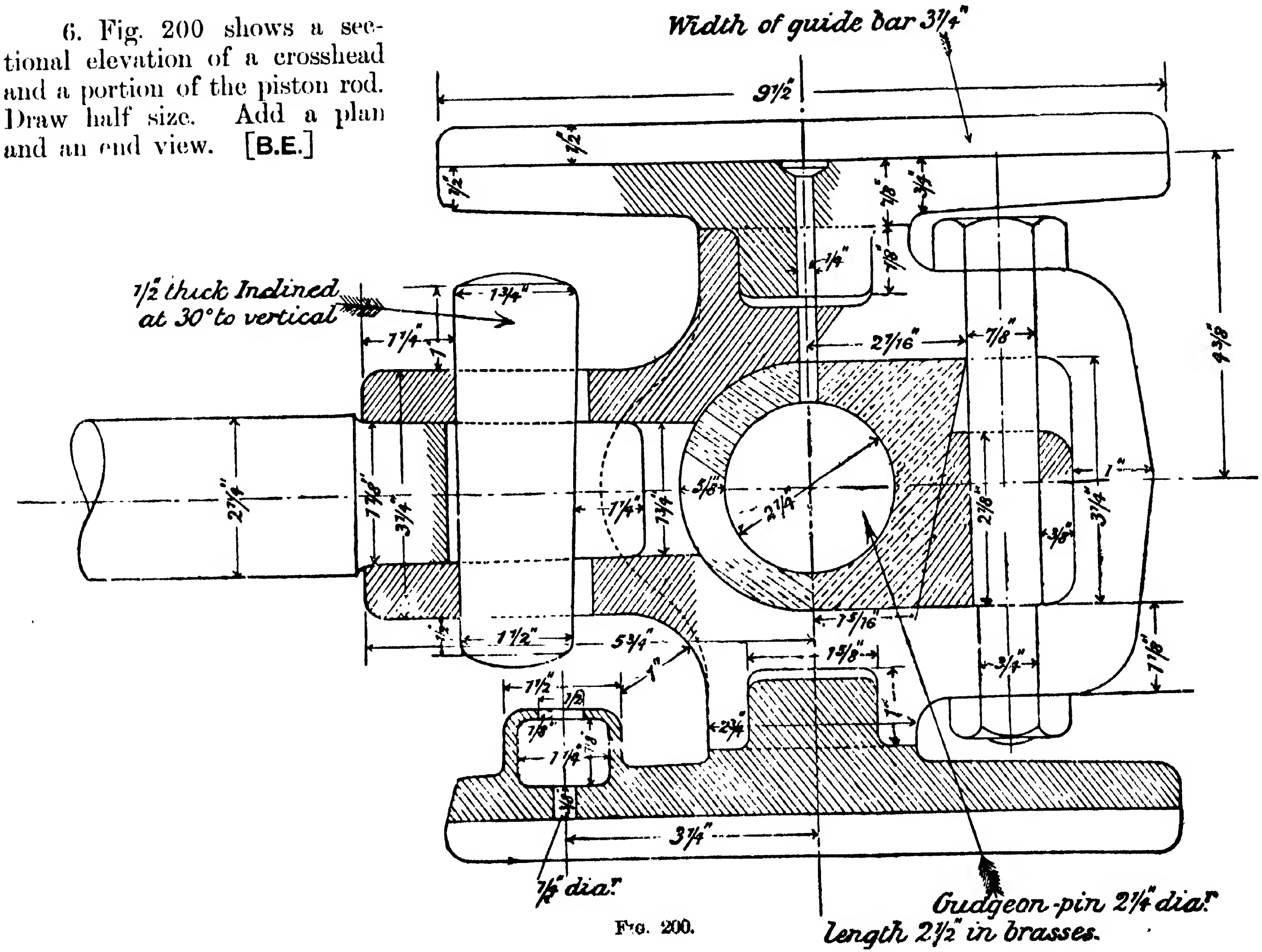


FIG. 200.

CHAPTER XII.

CONNECTING RODS.

Connecting rod. The connection between the crosshead and the crank pin of an engine is usually made by what is known as a *connecting rod*. The material used for such a rod is either mild steel or wrought iron of good quality.

The ends of the rod are usually referred to as the *small end* and the *large end* respectively. The former embraces the crosshead pin and the latter the crank pin.

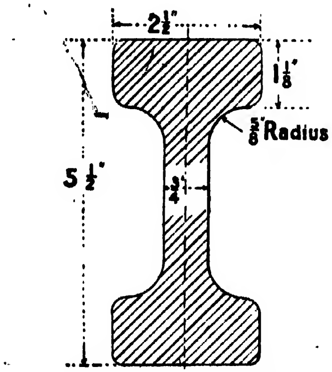


FIG. 201.—Cross Section of a Connecting Rod.

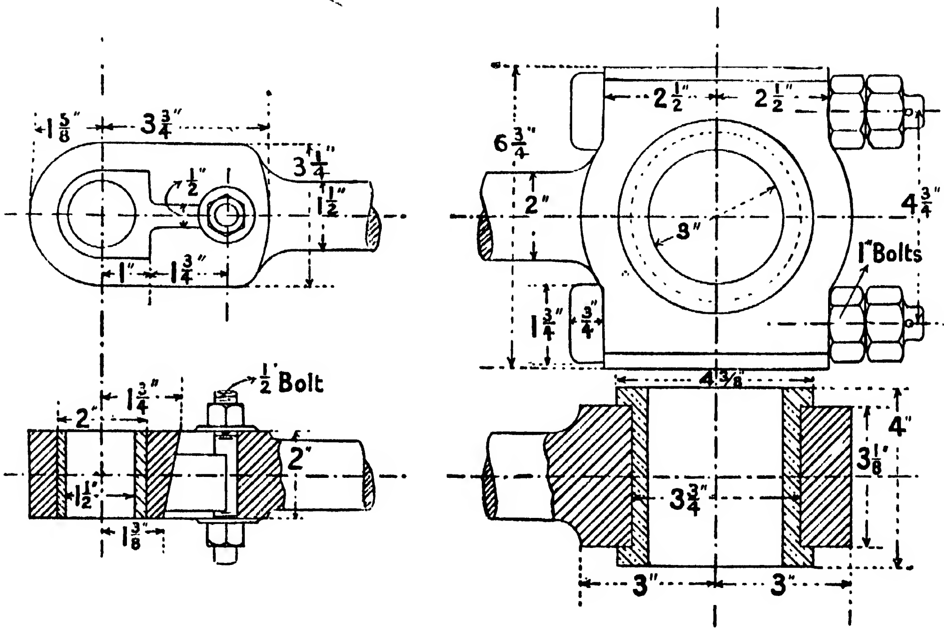


FIG. 202.—Details of Connecting Rod.

Example. Draw, full size, the cross section of a locomotive connecting rod (Fig. 201).

Example. Details of the ends of the connecting rod of the horizontal engine (Fig. 172) are shown in Fig. 202. Draw full size.

In slow moving engines the rod is frequently made of a circular form in cross section. In quick moving engines—locomotives, etc.—the rod usually consists of a tapering bar, or a bar rectangular in cross section as in Fig. 204. It may be I-shaped as in Fig. 201, which shows the cross section of a locomotive connecting rod, the distances between the centres being 10 ft.

Strap and cotter connecting rod end. In this form, the end of the connecting rod is made of a rectangular section. A strap of mild steel, or wrought iron, is made to fit this rectangular block, as in Fig. 203, and this strap also carries the brasses or steps forming the bearing. The strap may be secured by means of gibs and cotters. The arrangement of such a form of connecting rod may be seen by reference to Fig. 204.

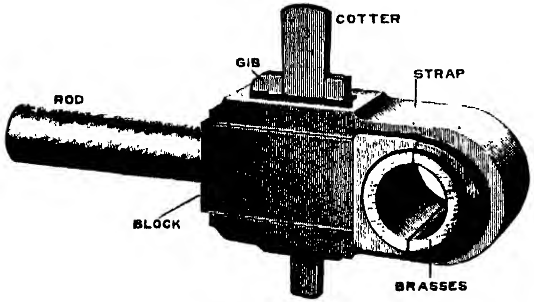


FIG. 203.

In Fig. 204 the large and small ends of a locomotive connecting rod are shown. In the small end shown at **I**, the open ends of the strap are held by means of two gibs, **G**, **G**; these also form bearing surfaces for the cotter **C**. The lubricator shown is forged solid with the upper part of the strap. The slacking back of the cotter is prevented by means of two small set screws; and to prevent injury to the cotter, shallow grooves are made, as shown, to receive the ends of the set screws.

The preceding arrangement is modified in the large end for the same connecting rod shown at **II** (Fig. 204). The strap is fixed by two well-fitting bolts; the back of the cotter is made in the form of a semicircle and fits a corresponding recess in the end of the rod. This recess is bored out to receive the cotter after the strap is bolted in position. The taper of the cotter is from 1 in 18 to 1 in 24, and the cotter is made to fit a shallow groove in the steel wedge, **W**. In addition to providing means of adjustment, the steel wedge, **W**, simplifies the fitting of the brasses.

As in the small end, the lubricator is forged solid with the upper part of the strap. The slacking back of the cotter is prevented by means of small set screws as shown.

Example. Draw the sectional elevation and plan of the ends of a locomotive connecting rod (Fig. 204). Scale $\frac{1}{4}$. Also draw, to a scale of $\frac{1}{8}$ full size, a sectional elevation and plan, showing the rod and ends. The complete distance between the centres is 6′ 6″.

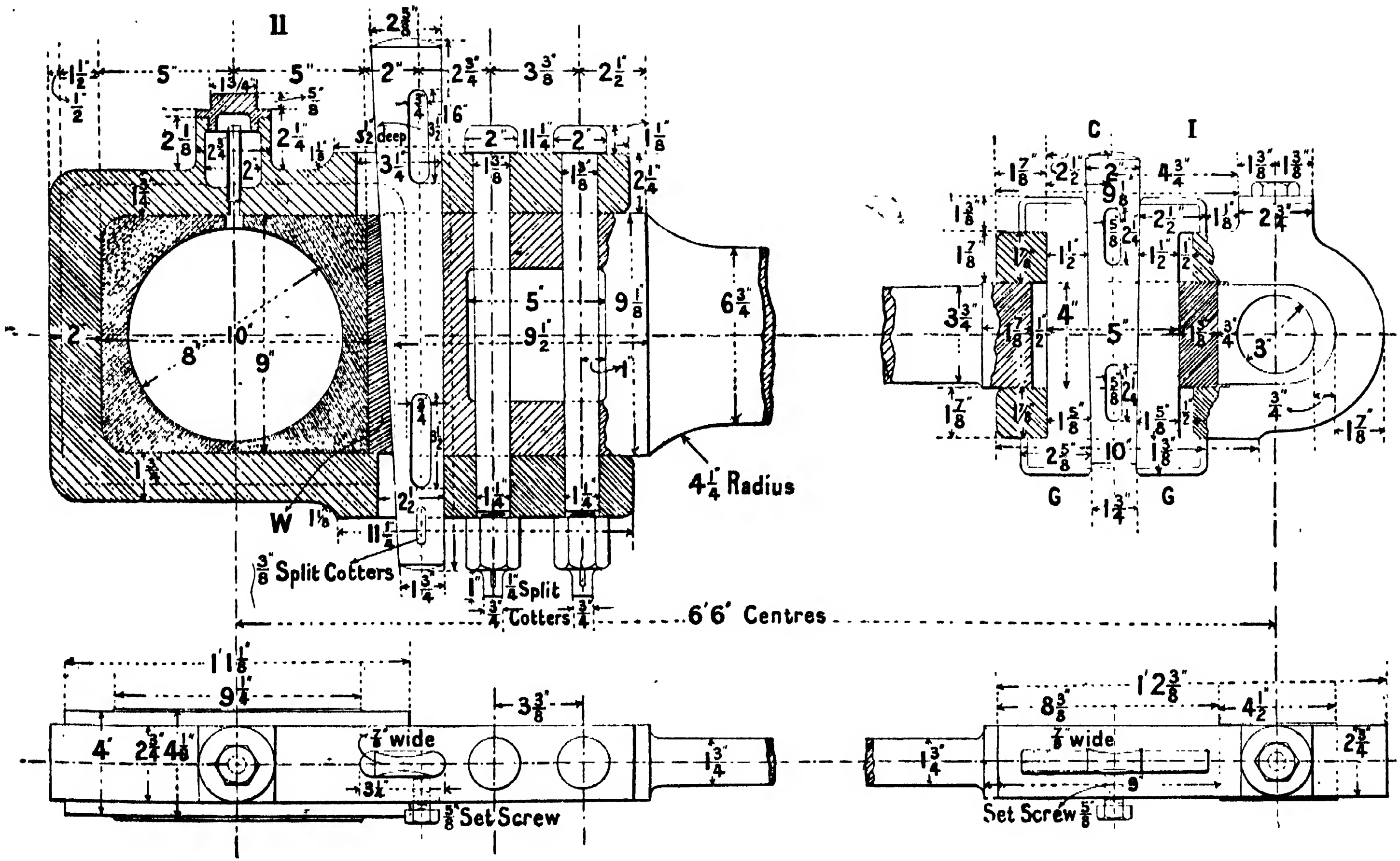


FIG. 204.—Locomotive Connecting Rod.

Box-end. In the preceding form of connecting rod end, there is the liability that the bolts or cotter may slacken back. To avoid this, the end of the rod carrying the brasses may be forged in one continuous

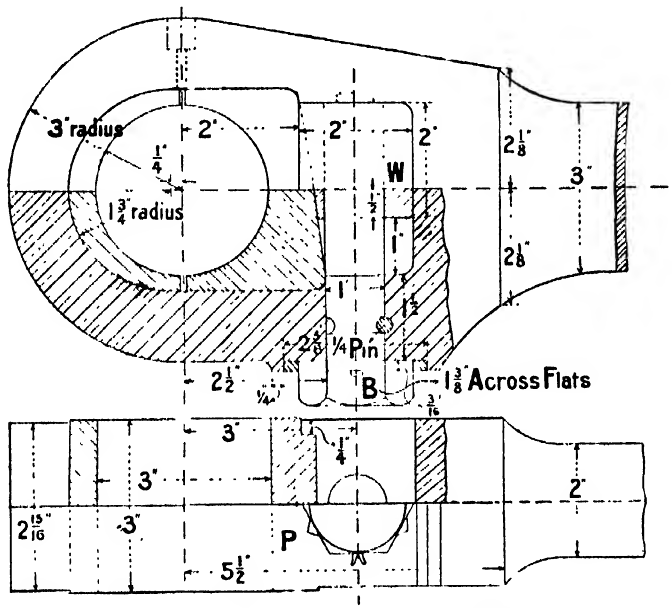


FIG. 205.—Box-end Connecting Rod.

piece with the connecting rod. The form thus obtained is known as the *box-end*. In this form (Fig. 205), no separate strap is required. The brasses are machined on the outside to fit the end of the rod and on the inside to fit the crank or crosshead pin. Rotation of the bolt, **B**, will force the brasses together, or release them by means of the inclined surface of the wedge, **W**. The bolt is secured by a locking plate, **P**, and a split pin.

Adjustment for wear. To adjust for wear the split pin and plate must be removed, and the wedge drawn up by means of a spanner. These are replaced when the adjustment is effected.

Example. Draw, full size, the two views of a connecting rod (Fig. 205). Also draw an end view.

Instead of the preceding arrangement, a modified type of "marine" end may be used. This is shown in

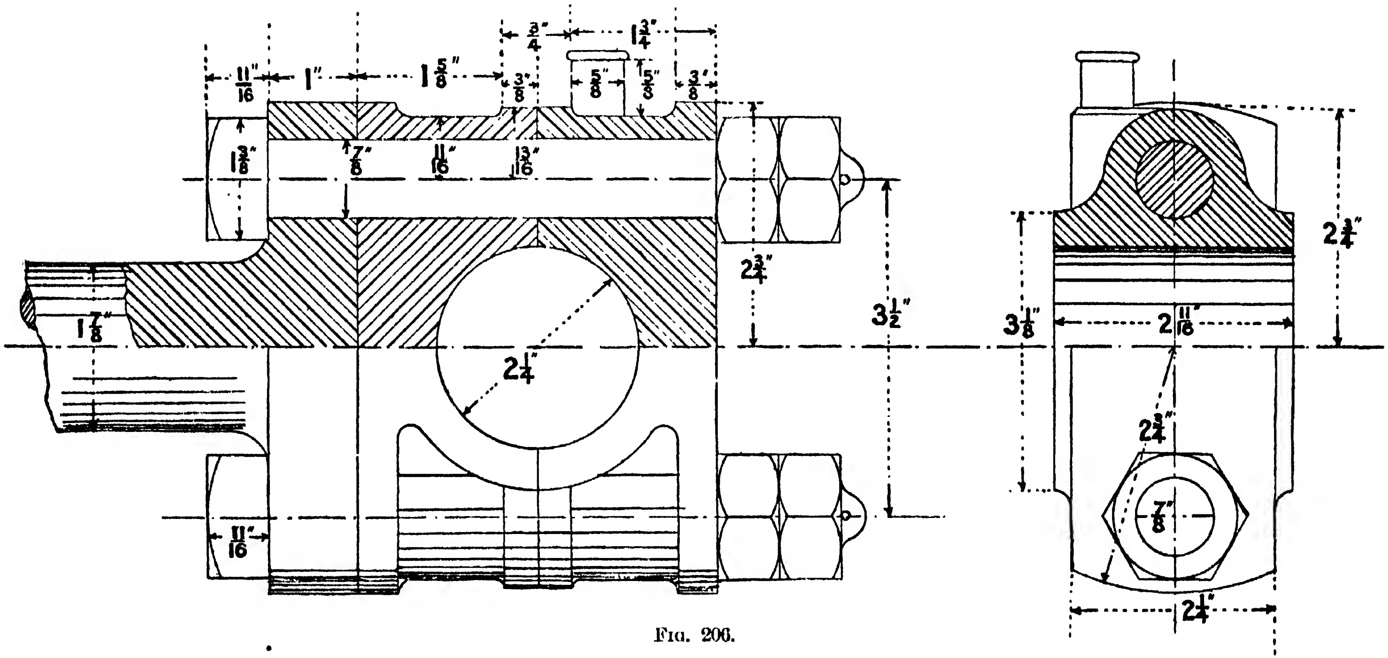


FIG. 206.

Fig. 206. The rod end is forged with a solid strap end and the brasses are secured by two bolts; these bolts which pass through the rod end and cap not only serve to secure the brasses, but also permit of adjustment.

Example. Draw, full size, the two views of a connecting rod end (Fig. 206). Also draw a plan.

Example. Draw the sectional elevation and plan of the two ends of a connecting rod (Fig. 207). *The dimensions are given in millimetres.*

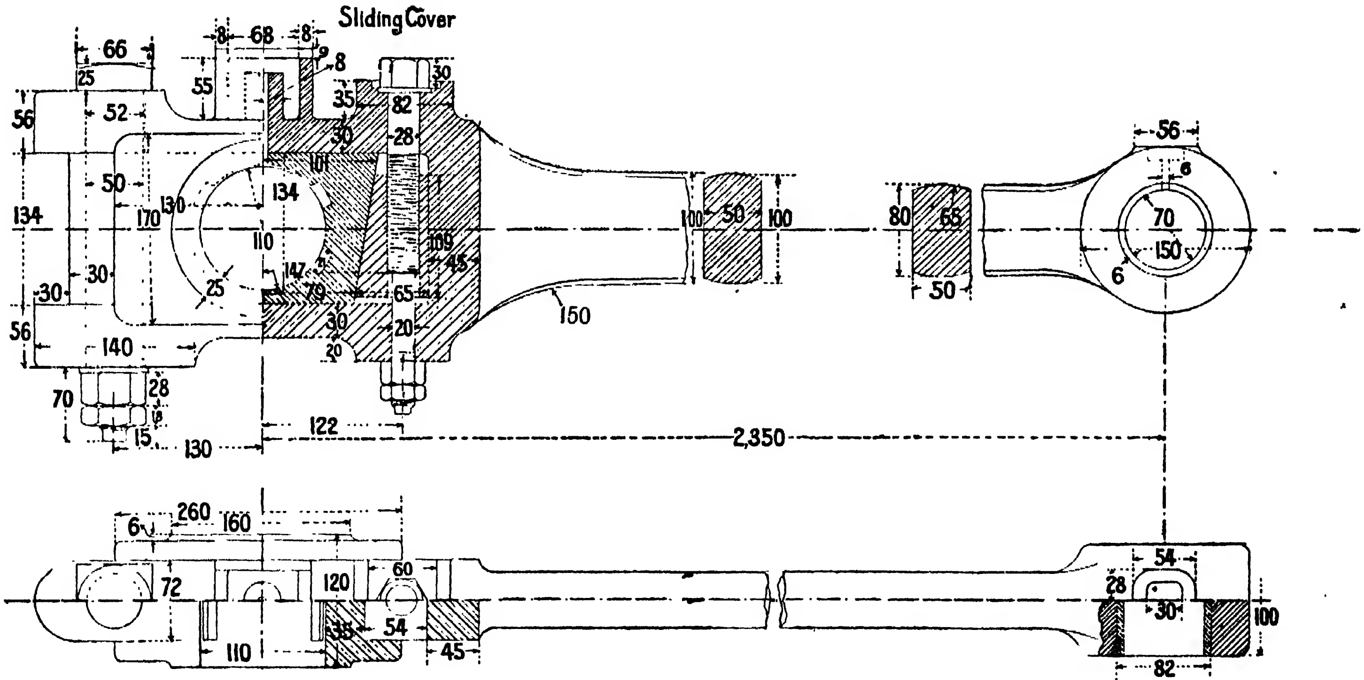


FIG. 207.

Marine form. In what is called the *marine form*, shown in Figs. 208, 209 210, the end of the rod is forged to a flat plate and a cap is made of the same shape, material, and thickness.

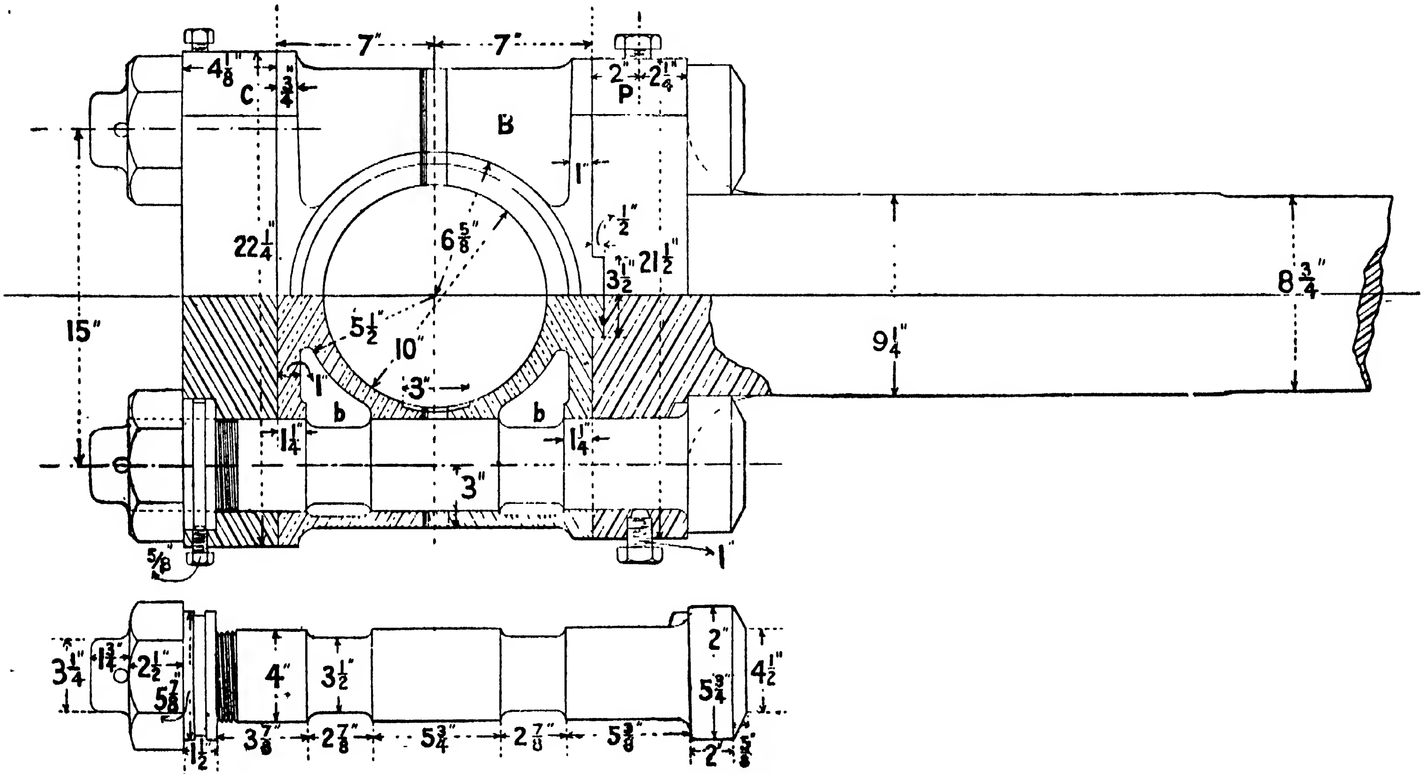


FIG. 208.—Connecting Rod End.

The two brasses are bored to fit the crank pin and machined along the surfaces in contact with the rod end and cap. These are fastened together by means of two bolts passing through holes bored in the end of the rod, the brasses, and the cap.

These bolts are prevented from rotating by means of snugs, one of which is shown in Fig. 208.

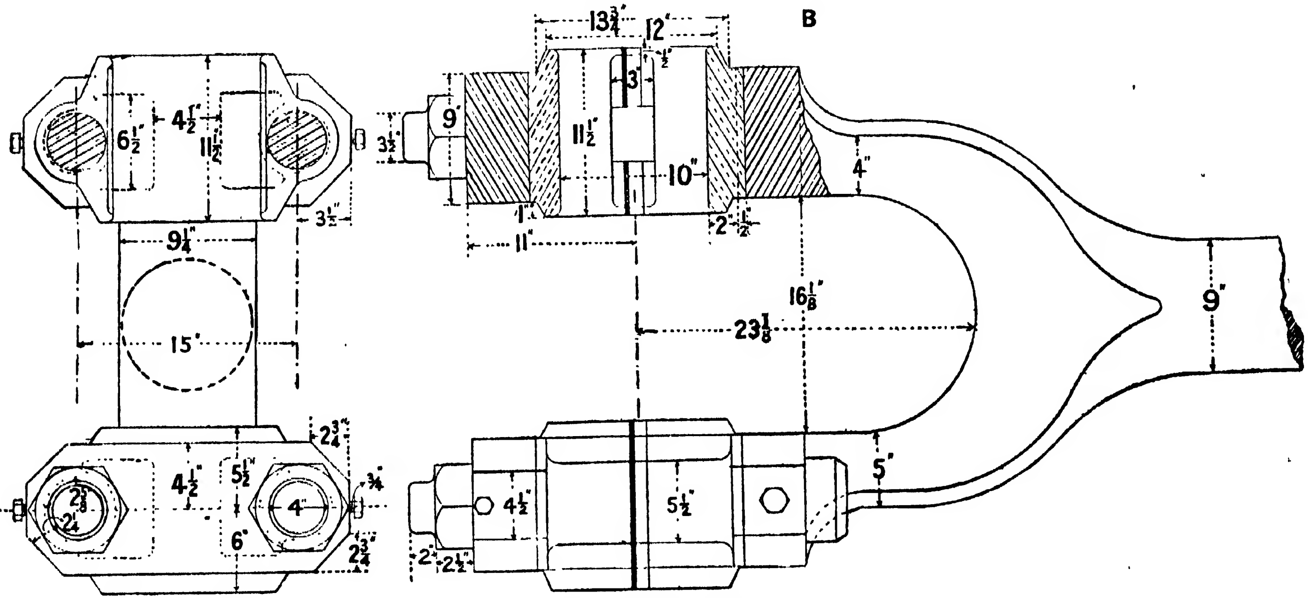


FIG. 209.—Connecting Rod End.

Small set screws passing through the end of the rod prevent the bolts from slipping back. In a similar manner, set screws, passing through the cap, form locking arrangements for the nuts, and in addition split pins are inserted. The weight of the brasses is reduced by hollowing out the material as at **b**, **b** (Fig. 208).

Example. Draw, $\frac{1}{4}$ size, the sectional elevations and plans of the large and small ends of connecting rod (Figs. 208, 209, 210).

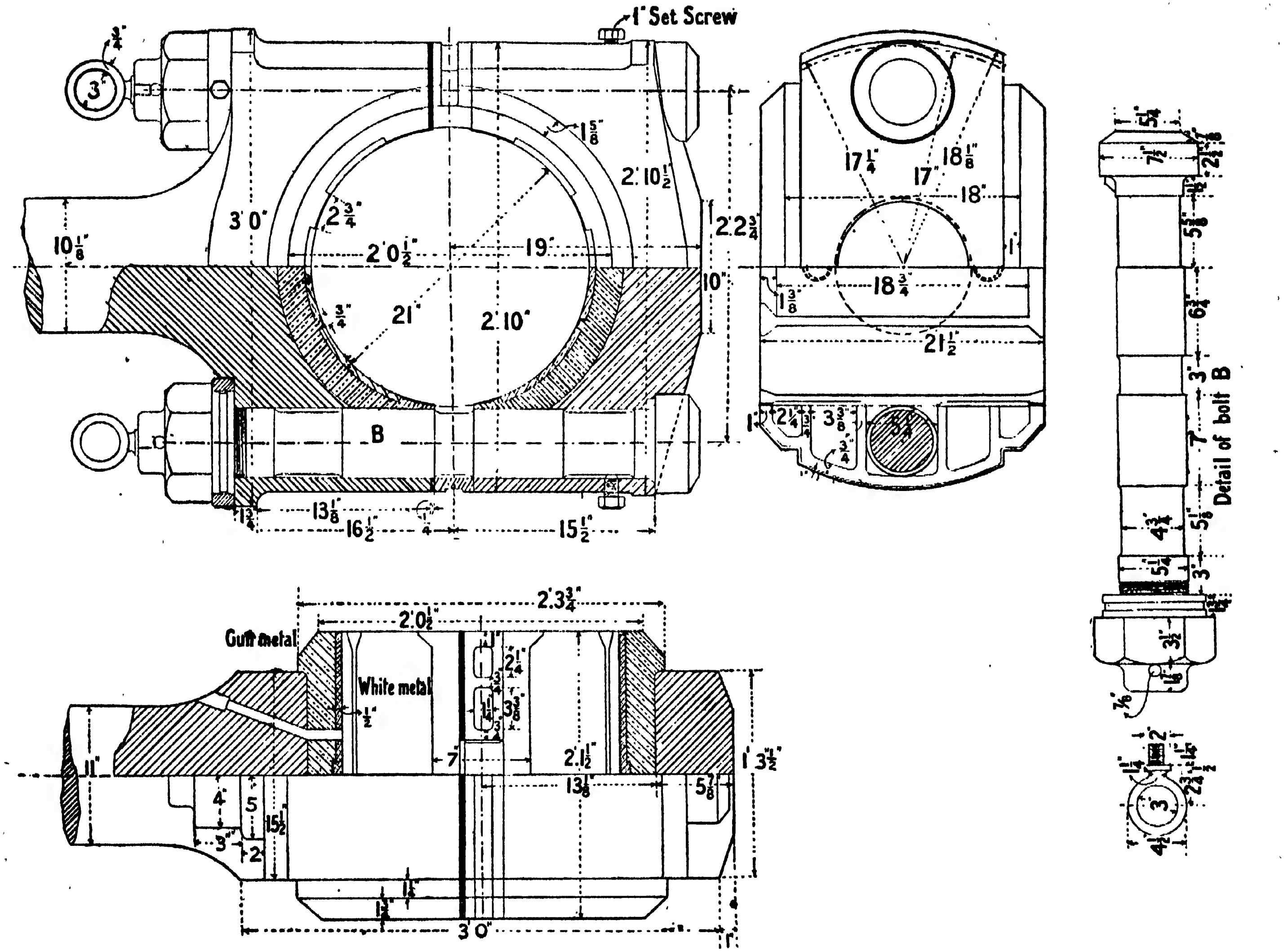
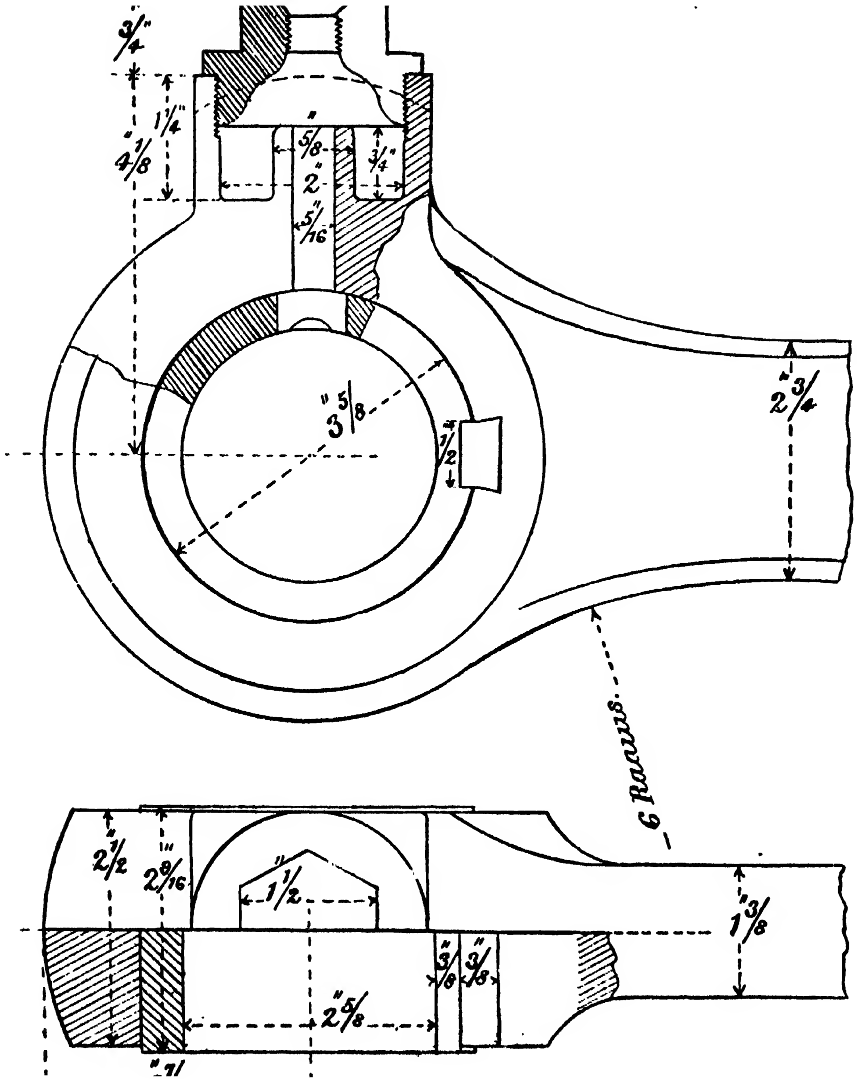


FIG. 210.—Connecting Rod End.



3/4"
1 1/4"
4 1/8"
5/8"
3/4"
2"
5/16"
3 5/8"
1/2"
2 3/4"
6 Radius.
2 1/2"
2 9/16"
1 1/2"
1 3/8"
3/8"
3/8"
2 5/8"

EXERCISES. XII.

1. Sketch two or three methods by which a cotter may be prevented from slacking back.

2. Distinguish between a key and a cotter. Draw an example of each, stating the purpose for which it is employed. Also state the amount of taper in each case. What is meant by the "draw of a cotter"?

3. Explain the advantage due to the use of a gib. Show by sketches the use of a cotter and a gib, also a cotter without a gib.

4. Show, by sketches, two forms of connecting rod ends. Explain how adjustment is made for the wear of the brasses.

5. Explain how the exact length of a connecting rod may be maintained whilst adjustment is made for the wear of the brasses.

6. Show, by sketches, the construction of a coupling rod end suitable for a locomotive.

7. Show, by sketches, a connecting rod end suitable for (i) a marine engine, (ii) a locomotive engine.

8. Sketch a connecting rod end with strap, gib, and cotter. Explain the use of the gib.

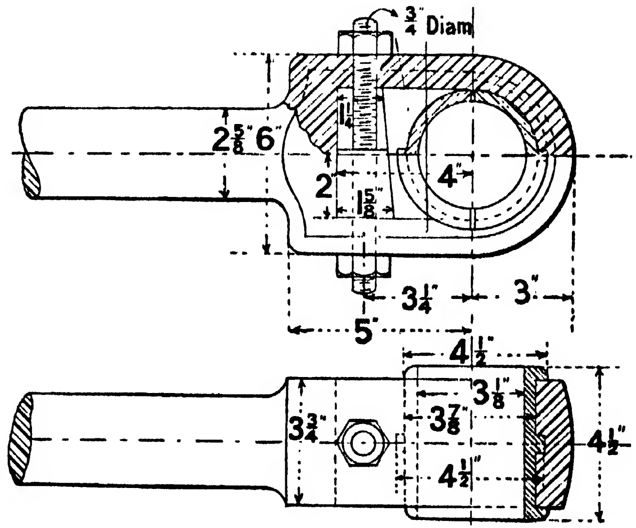


FIG. 212.—"Box End."

9. Fig. 211 shows one end of a coupling rod for a locomotive. Draw, full size, the two views shown; also draw an end view. [B.E.]

10. Two views of a simple form of "box-end" are given in Fig. 212. Draw half size and add an end view.

11. Fig. 213 shows a strap and cotter connecting rod end. Draw full size.

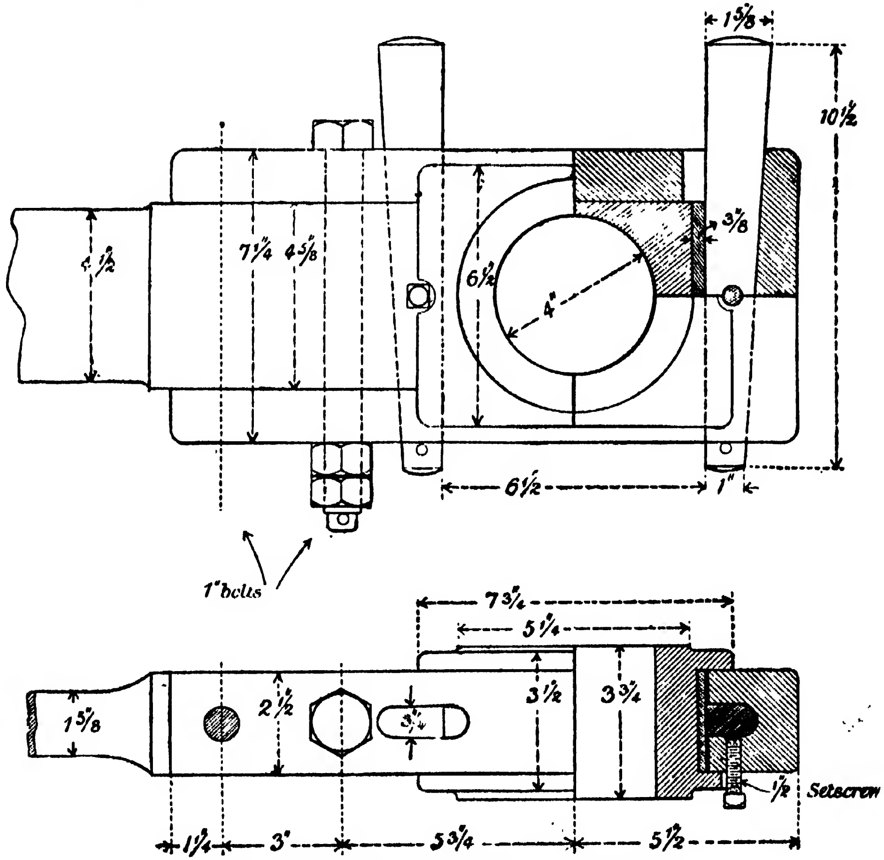


Fig. 213.—Strap and Cotter connecting Rod End.

12. A valve rod end for a marine engine is shown in Fig. 214. Draw half size. [B.E.]

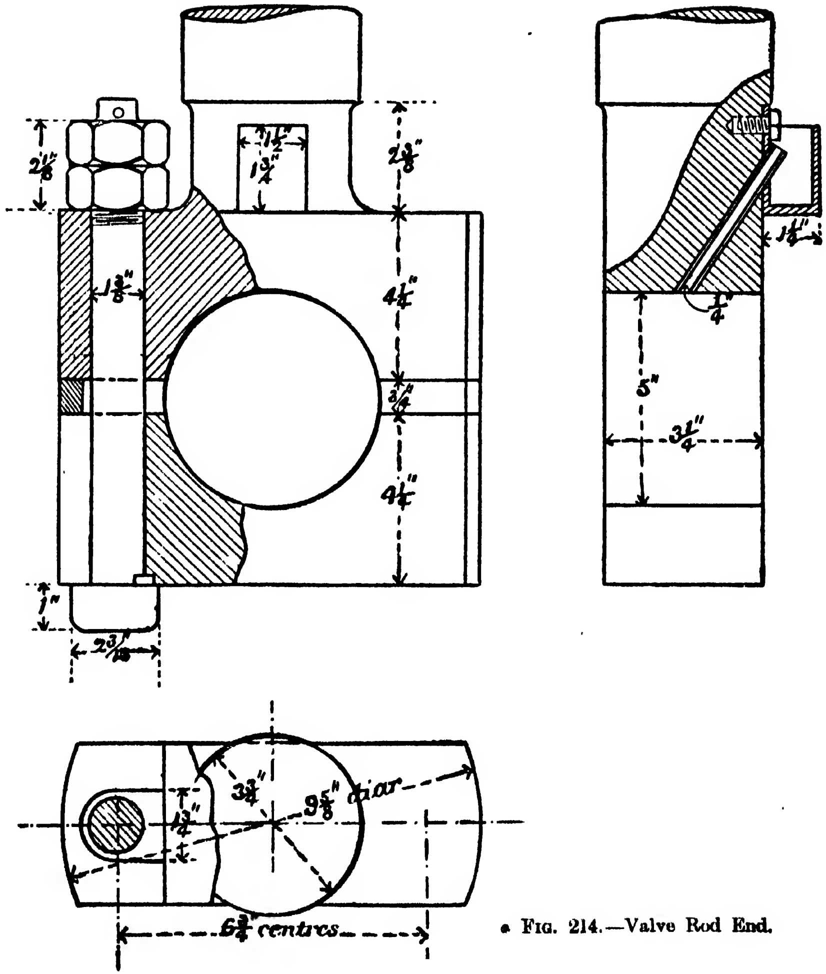


FIG. 214.—Valve Rod End.

CHAPTER XIII.

CRANKS AND ECCENTRICS.

Cranks. The forward and backward motion of the piston of an engine is converted usually into the circular motion of the crank shaft by means of some form of *crank*. The material used for such a crank may be cast iron, mild steel, or wrought iron. Of these the two named last are in most general use.

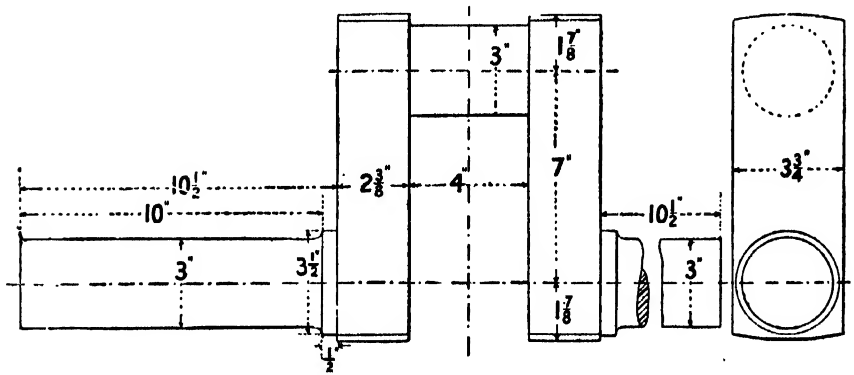


FIG. 215 Crank Shaft.

Fig. 215 shows a simple form of crank suitable for a small gas engine. The arrangement allows a bearing to be formed on each side of the crank pin.

Example. Draw the two views, half size, of the crank (Fig. 215). Also draw a plan.

In Fig. 216 two views of a crank shaft suitable for a portable engine, etc., are shown. The cranks and crank pin are formed by bending the crank shaft. This plan, like that in the preceding case, allows a bearing to be formed on each side of the crank pin.

Example. Draw, half size, the two views of the crank shaft (Fig. 216). Also draw a plan.

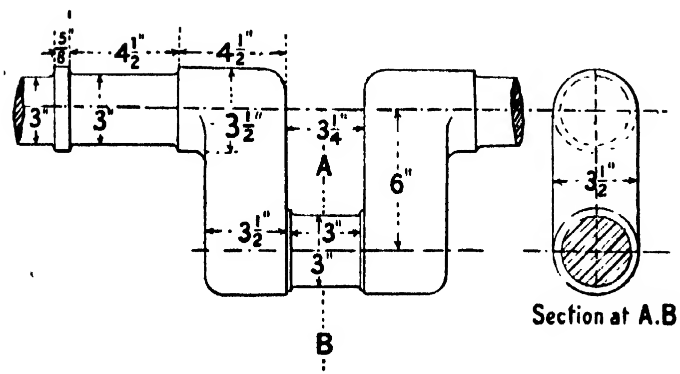


FIG. 216.

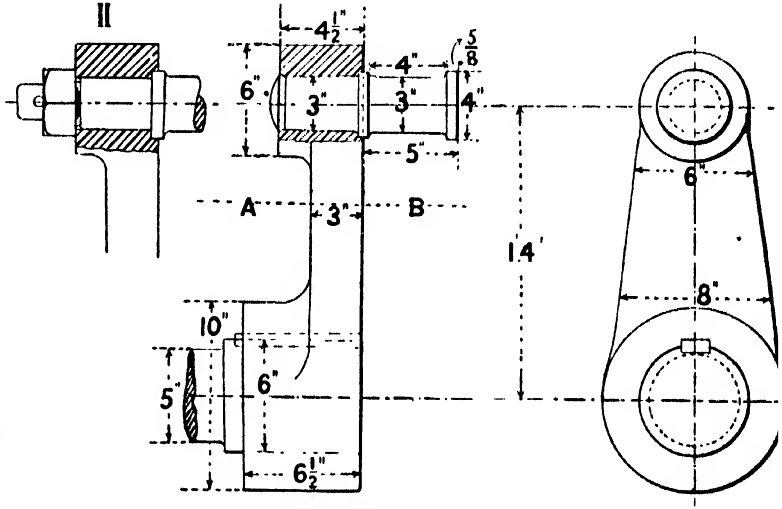


FIG. 217.

Cranks of larger size usually consist of forgings which are fastened to the crank shaft. Two methods of fastening commonly used for the purpose are known as *forcing* and *shrinking*. In the first named, the hole in the crank is bored slightly smaller than the crank shaft, the key-ways are cut both in the shaft and the crank, and the crank is then forced to its place by hydraulic pressure. The crank pin is fastened to the crank in a similar manner.

Example. Draw, $\frac{1}{3}$ full size, the two views of the overhung crank (Fig. 217). Draw a sectional plan along the line **AB**.

In the second method, advantage is taken of the expansion that metals undergo when heated. Thus, if, as before, the hole is made slightly smaller than the shaft, then, when heated, the crank can be passed to its place, care being taken to keep the key-ways in line during the process of cooling. In this manner the crank shaft is gripped firmly by the crank, and finally a key is fitted carefully and driven tightly into place.

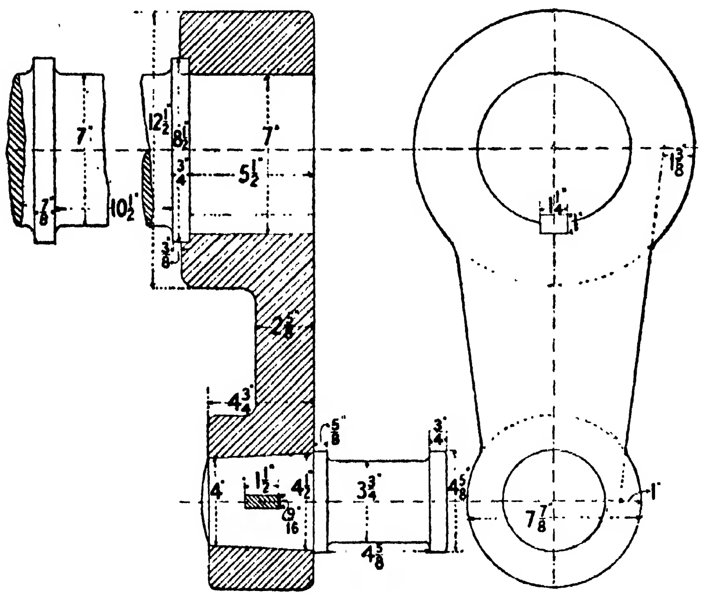


Fig. 218.

The crank pin may be fastened in like manner, and, in addition, it may be riveted over as shown in Fig. 217.

A better method than that of riveting is to increase the length of the part of the pin which fits the hole in the crank, and to make this part long enough to receive a thin nut, as at **II** Fig. 217. Instead of the preceding plan, the hole in the crank may be made taper and the crank pin secured by a cotter, as in Fig. 218.

Example. Draw, $\frac{1}{3}$ full size, the two views of the crank (Fig. 218). Distance from centre of crank shaft to centre of crank pin 16″.

In the overhung cranks referred to, it will be evident that a considerable part of the weight of the crank is on one side of the centre of the crank; hence unbalanced forces may be introduced—especially in the case of large cranks. These forces, which may be negligible in slow moving engines, are of importance in those moving at a comparatively high rate of speed, and give rise to injurious vibrations. To avoid these disturbances, various plans of balancing are adopted. One method is to prolong the crank web beyond the crank shaft.

Another plan is to place a weight between two arms of a wheel to which the crank is attached, such as the balance weight between two arms of the driving wheel of a locomotive. Another form consists of a

cast-iron disc in which a weight, W, can be placed along the line joining the centres of the crank pin and the crank shaft produced. Two views of such an arrangement are shown in Fig. 219. The crank shaft is

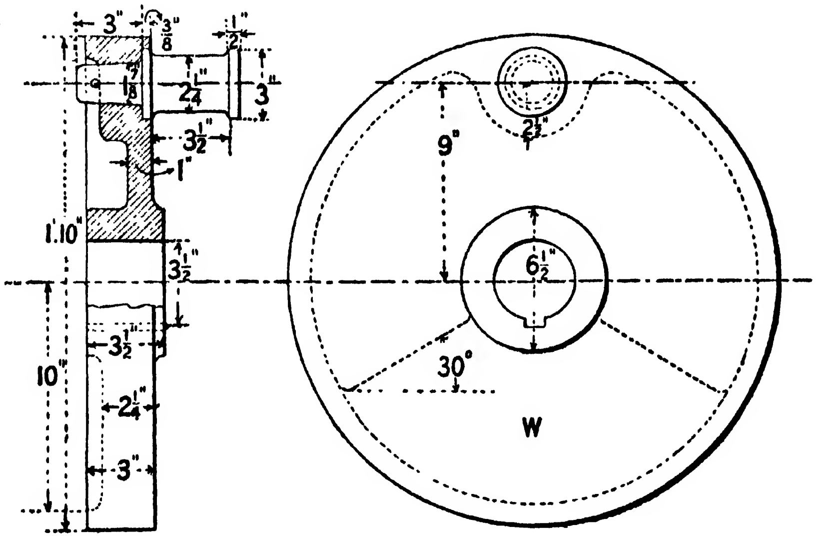


FIG. 219.—Disc Crank.

of mild steel, $3\frac{1}{2}''$ diameter, the hole bored out to a slight taper, and the disc is then forced on to the shaft with considerable pressure. and further secured by a sunk key. The crank pin is made a tight fit in the disc, and secured by a taper pin, $\frac{1}{2}''$ diameter.

Example. Draw, to a scale of $4''$ to $1'$, the two views of a disc crank (Fig. 219). Draw also a plan.

Two methods adopted for lubricating a crank pin are shown at **I** and **II** (Fig. 220). At **I** a hole is bored in the direction of the length of the pin and outwards, as shown, to the bearing surface. At **II** the oil

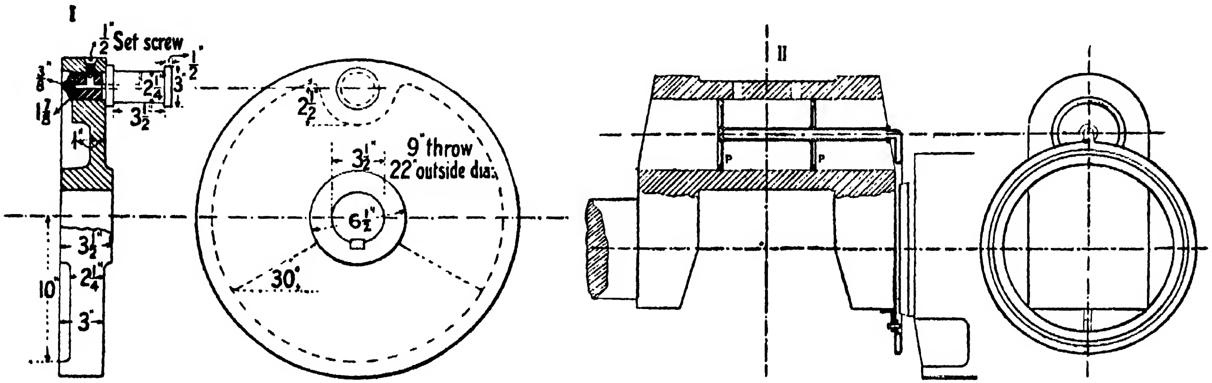


FIG. 220.—Lubricating Crank Pin.

is forced along the pipe shown, and passes through the two holes indicated; escape along the axis of the crank pin is prevented by the two small pistons depicted at P, P, in the diagram.

Built-up crank shafts. Built-up crank shafts are generally used for the comparatively large shafts in the mercantile marine. The two webs—or crank arms—crank pin, and the two parts of the crank shaft, are made separately and afterwards fastened together. The material may be fluid compressed steel forged by hydraulic presses. The holes in the webs are punched and afterwards forged on mandrils. The process of fastening the parts together is briefly as follows. One of the webs, A or B, (Fig. 221) is shrunk on to the crank shaft, care being taken to keep the key-ways in line; after cooling, a key is fitted and driven

tightly into place; instead of a key, a hole for a pin may be drilled and then the pin is driven tightly into place.

The remaining web is secured in like manner. The two holes for the crank pin are next put together and heated, and whilst hot the crank pin is inserted.

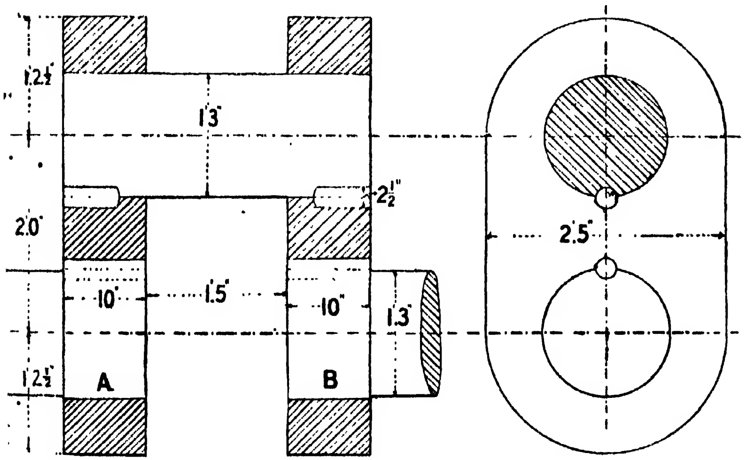


FIG. 221.—Built-up Crank Shaft.

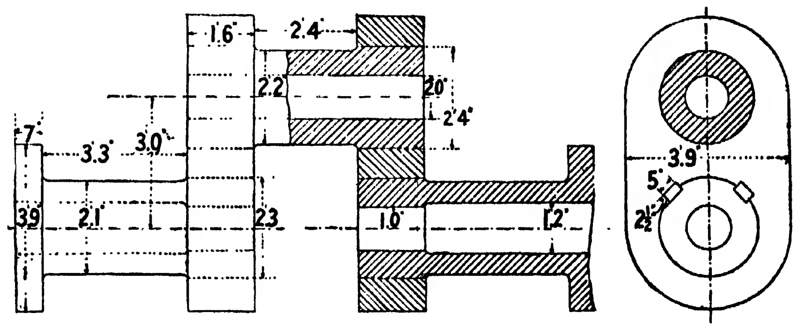


FIG. 222.

Example. Draw, half size, the two views of a built-up crank shaft (Fig. 221).

Example. Draw, $\frac{1}{3}$ full size, the two views of one of the crank shafts for the *City of Rome*, also draw a plan (Fig. 222).

Eccentric. When a crank is used, the crank shaft must be divided to enable the connecting rod—one end of which is fastened to the crank pin—to pass the centre of the crank shaft. This expedient is unnecessary when an eccentric—which may be described as a particular form of crank in which the crank pin is made large enough to include the crank shaft—is used.

Thus, let **A** (Fig. 223) denote the centre of the crank pin, and **B** the centre of the crank shaft. With **A** as centre and a radius large enough to include the crank shaft, draw a circle. Such a circle will correspond to what is called the *sheave of an eccentric.* This circle when encircled by a suitable strap may be made to give a reciprocating motion to a valve or other reciprocating piece.

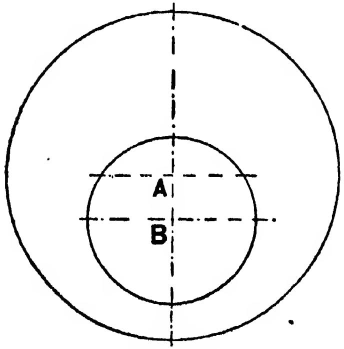


FIG. 223.

The sheave may be made either in one or in two parts. In the former case it must be passed over the end of a shaft; and this, owing to projections, may be difficult or impossible. In such cases the sheave is made in two parts and fastened together by bolts or studs.

The sheave is fastened temporarily in position on the shaft by means of one or more set screws. Afterwards, when its position is ascertained definitely, it is keyed fast to the crank shaft.

The eccentric, unlike the crank, cannot be used for the conversion of reciprocating into circular motion; but it is of great utility in the conversion of circular into reciprocating motion. A familiar example is furnished by the conversion of the circular motion of the eccentric into the reciprocating motion of the slide valve. The materials used are generally as follows. When the eccentric is of comparatively small size, the sheave and strap may be made of brass. In the larger sizes the material used is cast iron or steel, and friction is reduced by using a brass liner.

A common form of eccentric is shown in Fig. 224. The sheave and strap are made of cast iron and a brass liner is used. The sheave is made in two parts, fastened together by means of two cotter bolts. The halves of the strap are connected by bolts and the unscrewing of the nuts is prevented by lock nuts. In addition, small split pins are inserted near the end of each bolt.

Distance pieces, **P**, **P**, are provided for adjustment. These may be made of hard wood, leather, gun-metal, etc., and the adjustment is made by reducing their thickness.

EXERCISES. XIII.

1. For what purpose are cranks used? Indicate by sketches two forms of crank suitable for a steam engine.

2. State the process by which a wrought-iron crank is fastened to the crank shaft; also explain how the crank pin is fastened to the crank.

3. Explain, by sketches, the chief difference between a crank and an eccentric. What is the throw of an eccentric?

4. Show, by sketches, a wrought-iron overhung crank and a disc crank. What advantages are obtained by using the latter?

5. By means of a sketch and a description, show how the two parts of an eccentric sheave are joined together when the sheave cannot be passed over the end of the shaft.

6. Sketch in section the construction of an eccentric sheave, strap, and rod, the sheave being made in two parts. Show how the sheave is fixed to the shaft and explain why each portion of the eccentric is made separately from the rest.

7. When the eccentric strap shown in Fig. 227 becomes loose by wear, how is it adjusted? What is the travel of the slide valve, the spindle of which is connected directly to the end of the eccentric rod? [B.E.]

8. With the aid of sketches, describe how you would fix the portions of the eccentric strap (Fig. 224) in a lathe for the purpose of turning the interior surface. Also point out where the eccentric and strap will wear most rapidly and describe how it may be refitted when worn.

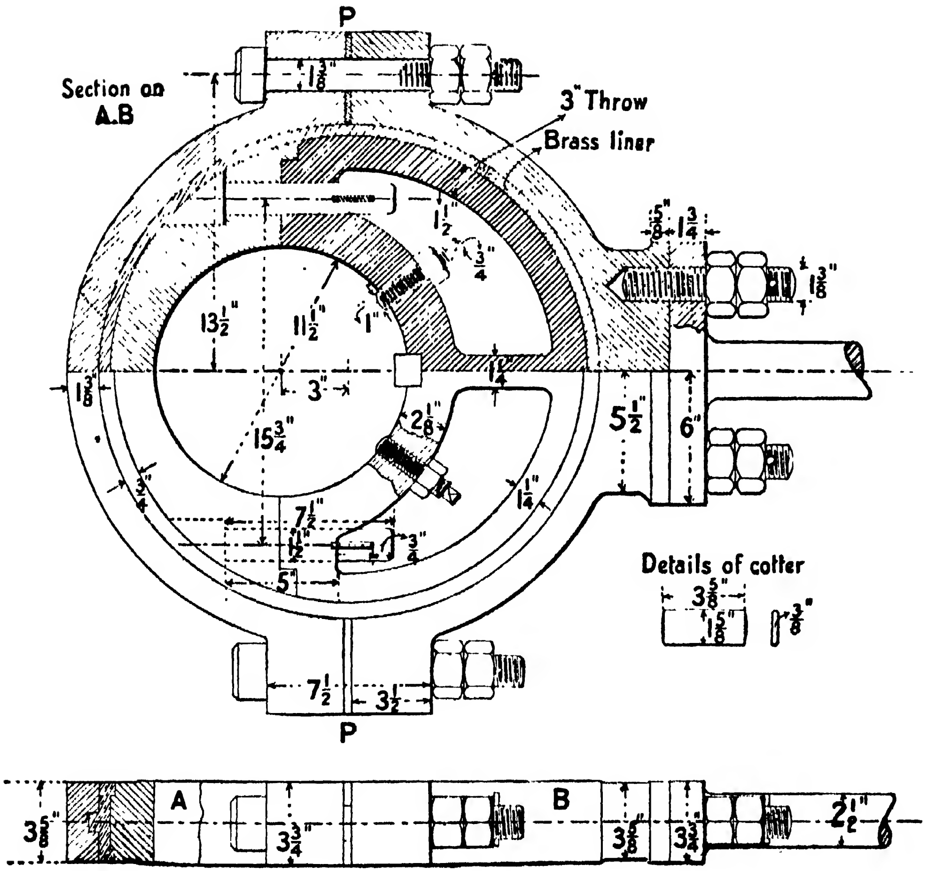


FIG. 224.—Eccentric.

8*a*. Draw, $\frac{1}{4}$ size, the sectional elevation and plan of an eccentric (Fig. 224). Also draw an end view.

9. Fig. 225 shows a locomotive crank shaft. Do not draw the parts separated from one another as in the diagram, but draw one end of the shaft with the crank arm and the eccentric sheave in place. Scale half size. [B.E.]

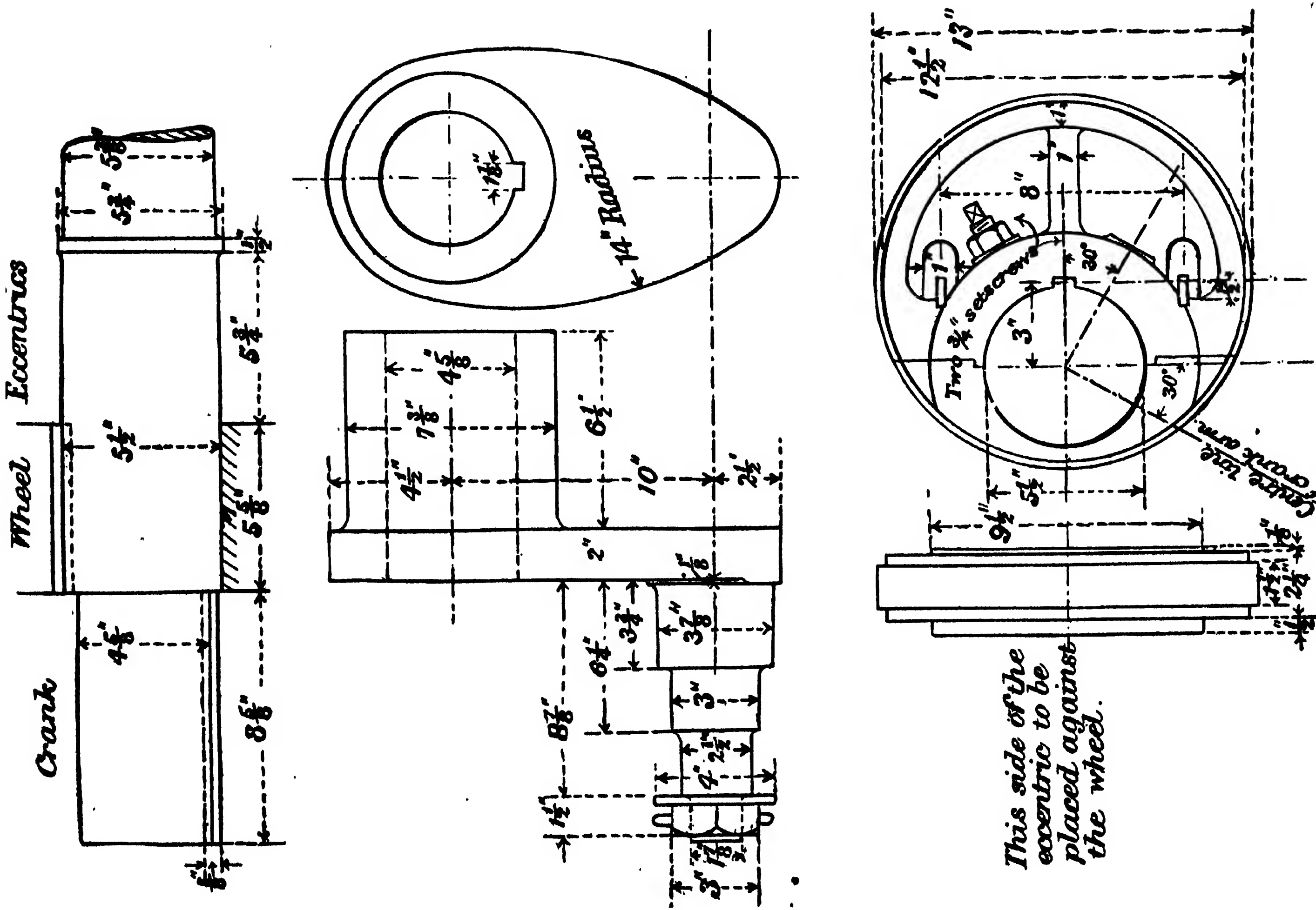


FIG. 225.—Locomotive Crank Shaft.

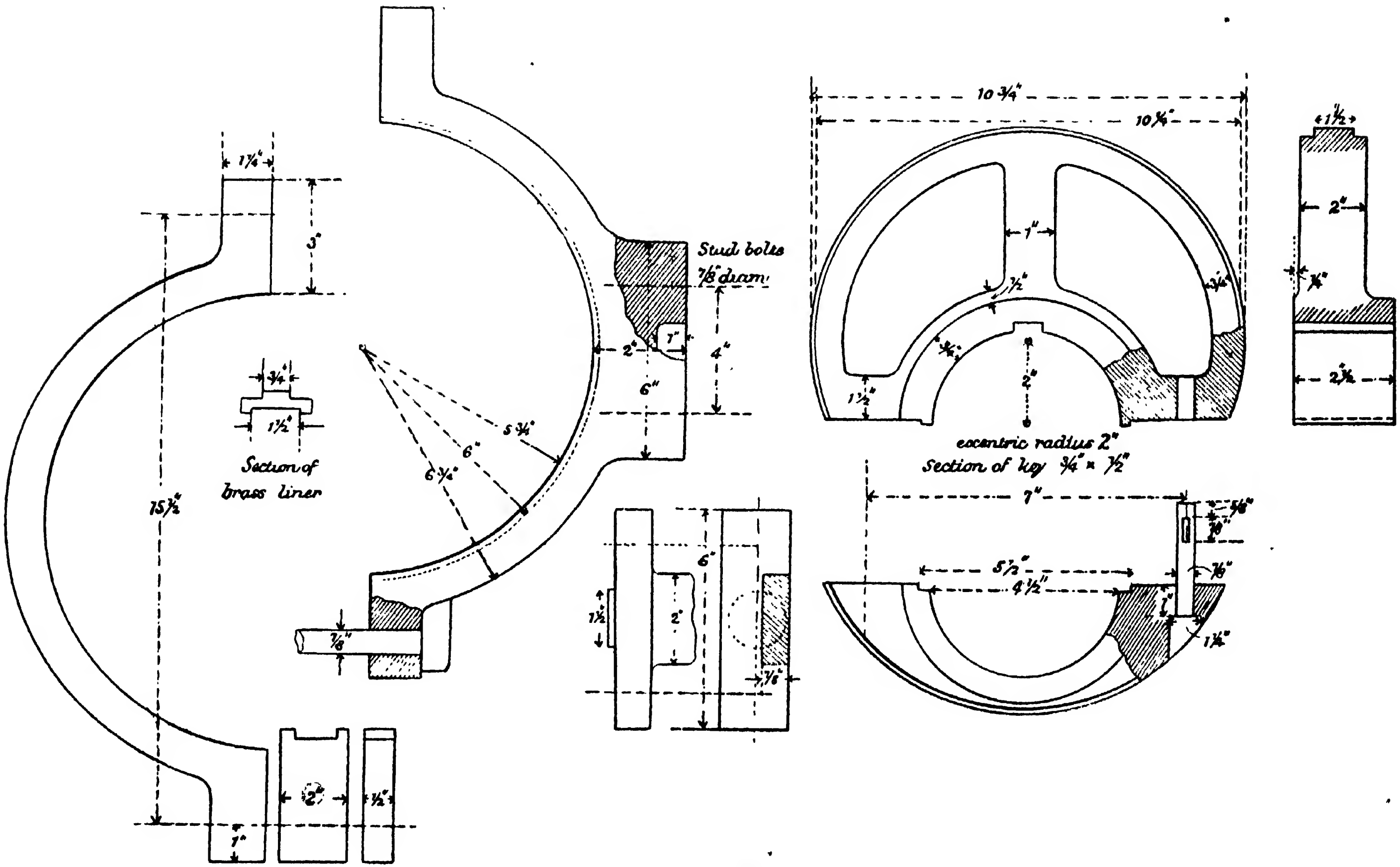


FIG. 226.—Details of an Eccentric.

10. Eccentric for a steam engine. The diagram (Fig. 226) shows the two portions of the sheave and the strap disconnected from one another. Draw the parts fitted together and also insert the strap end of the eccentric rod. Scale $\frac{1}{2}$. [B.E.]

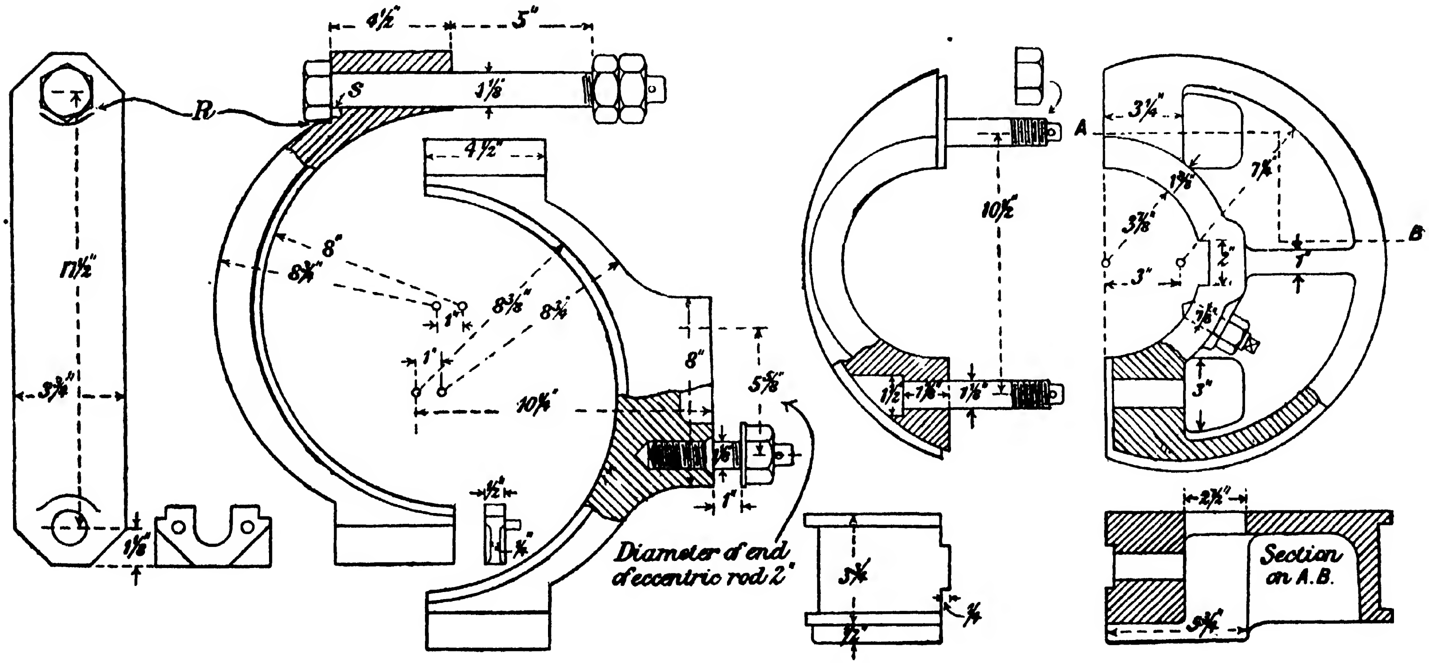


Fig. 227.—Details of an Eccentric.

11. Eccentric. The diagram (Fig. 227) shows the various portions of an eccentric. Draw a sectional elevation and plan of the parts fitted together. Scale half size. [B.E.]

CHAPTER XIV.

VALVES. SLIDE VALVE. SAFETY VALVE.

Valves. The object of a valve is usually to open or close a passage through which steam or other fluid can pass from one place to another. The fixed part, or seating on which the valve rests, is formed usually in the passage, especially in the case of small brass valves. In larger valves it is generally made separately; the outside of the seating is then made slightly taper and fitted accurately and tightly into a corresponding taper opening in the passage. This method of fixing allows the valve and seating to be made of brass, though the passage in which it is placed may be made of cast iron.

Valves of various kinds are used so largely by engineers, and there are so many varieties, that it is a difficult matter to make a suitable selection, and it is only possible to refer to a few of the more important. Roughly, they may be divided into three classes, viz.:

(1) Those opened and closed by hand.

(2) Valves which are opened and closed by self-acting mechanism.

(3) Valves opened and closed by the pressure of a fluid.

An example of the first kind is furnished by the ordinary stop, or throttle, valve of an engine, an ordinary straight-way cock, etc. (Fig. 228). A familiar instance of the second kind occurs in the slide valve of an engine and in regulating or throttle valves (Fig. 241). India-rubber valves, etc., are examples of the third kind as well as being instances of non-return valves.

Example. Draw, half size, the two views of a 3″ stop valve (Fig. 228).

The lift of a valve is usually made equal to one-quarter of the diameter of the valve. Thus, for example, the diameter of the stop valve on a boiler is usually the same as the diameter of the supply steam pipe, and the maximum lift of the valve is equal to one-fourth its diameter.

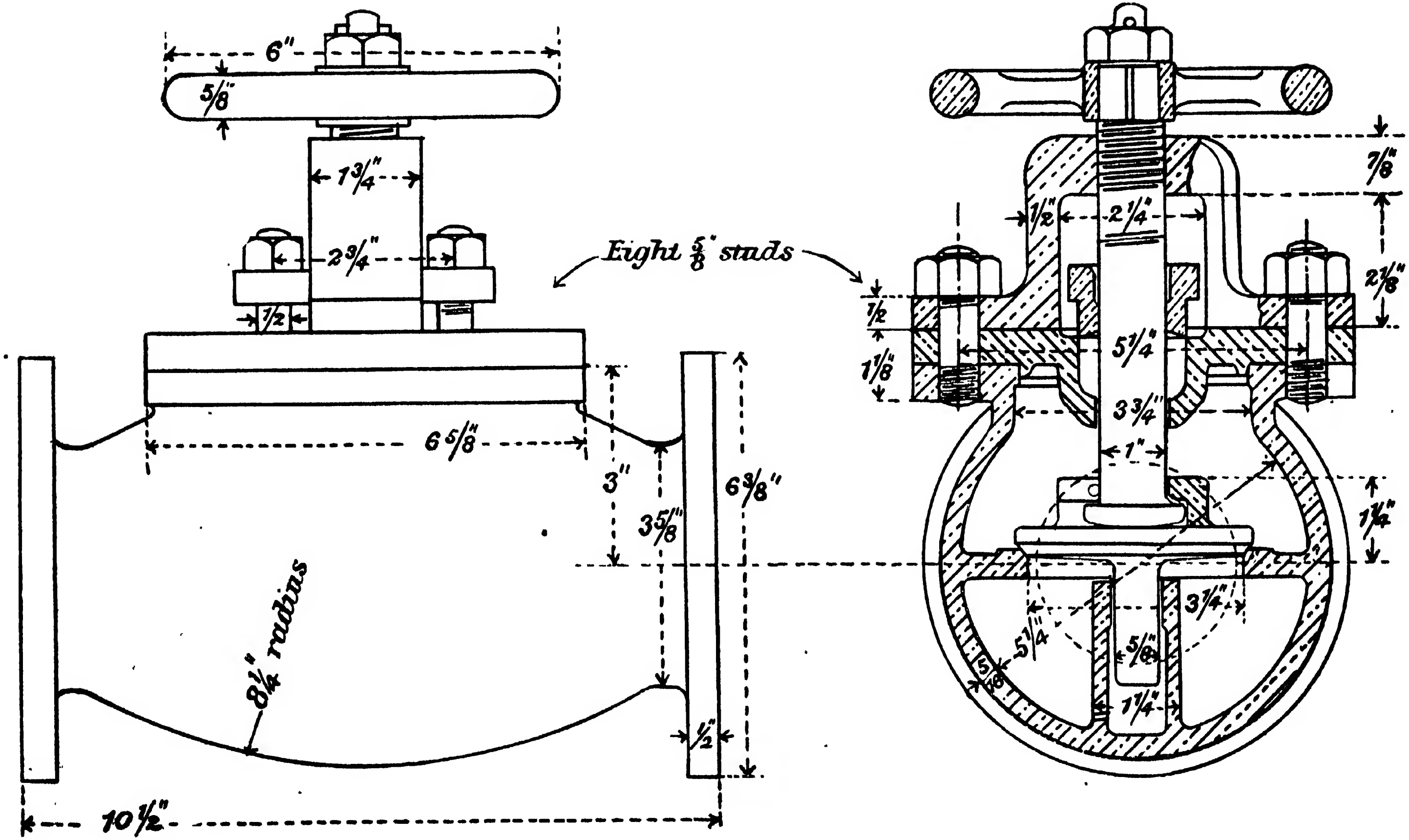


FIG. 228.—Stop Valve.

Let **d** denote the diameter and x the lift of the valve. The cylindrical area of escape, when the valve is opened a distance x, is $\pi x\mathrm{d}$, and this must be equal to the area of cross-section, or bore, of the pipe, *i.e.* to $\frac{\pi}{4}\mathrm{d}^2$.

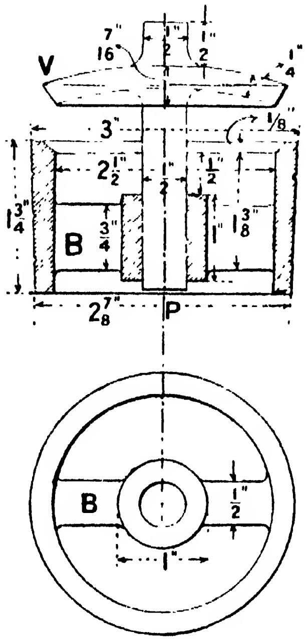


FIG. 229. Conical Disc Valve.

$$\text{Hence } \pi x\mathrm{d} = \frac{\pi}{4}\mathrm{d}^2$$

$$\therefore\ x = \frac{\mathrm{d}}{4}$$

Conical disc valve. In Figs. 229, 230, examples of what are called *conical disc valves* are shown. The essential difference between the two consists in the manner in which the valve **V** is guided during its rise and fall. Thus, in Fig. 229, in the fixed part of the valve called the *seat* or *seating*, a bar or bridge **B**, forming part of the seating, passes across the centre; and at the middle of this bar, a hole of the size of the pin is made. This forms a guiding surface in which the pin **P** moves freely. The under surface of the valve **V** is made conical, the inclination being about 45°, and fits into a corresponding conical part on the seating. The width of the conical part is small, not exceeding $\frac{1}{16}''$ or $\frac{3}{32}''$.

The valve and seating, when of comparatively small size, are both made of brass. To reduce the weight of the valve, the upper surface is hollowed out in a manner indicated by the dotted curves of Fig. 229.

Another method of guiding the valve is shown in Fig. 230; it consists of three *wings* or *feathers*, radiating from the centre of the valve. The edges of these feathers are turned in the lathe so that they fit quite easily and loosely into the hole in the valve seating. The notches, shown at **N** at the junction of the feathers, and the face of the valve not only allow a better opening for steam or water when the valve is lifted, but also provide clearance for the lathe tools during the process of turning and the preparation of the surfaces in the lathe.

In all cases suitable stops are provided to prevent the valves rising too far.

Example. Draw the sectional elevations and plans of the two disc valves (Figs. 229, 230). Full size.

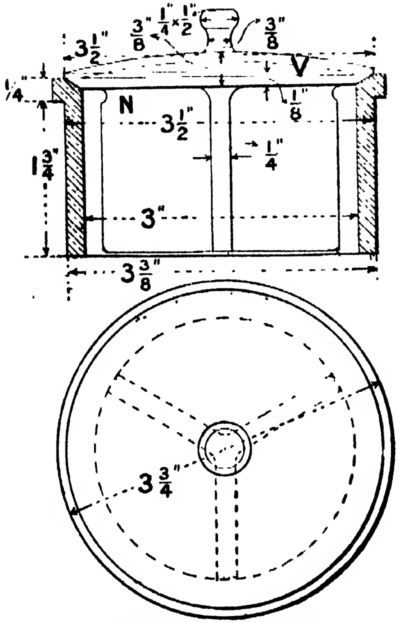


FIG. 230.—Conical Disc Valve.

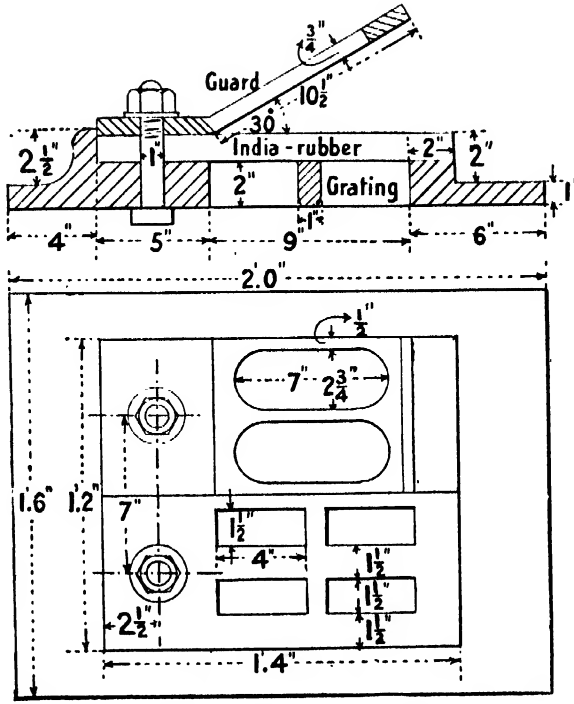


FIG. 231.—India-rubber Flap Valve.

India-rubber flap valve. In this form of valve, a rectangular piece of india-rubber is held firmly by one end as indicated in Fig. 231. In the plan shown, one-half the guard is removed to show the seating of the valve. The object of the guard is to prevent the india-rubber from rising too far.

Example. Draw the two views of the valve (Fig. 231). Also draw an end view. Scale ¼.

Slide valve. In its simplest form, the slide valve consists of a box-shaped casting, in which the faces **A, A** are planed accurately and made to slide backwards and forwards on a similarly prepared surface in the steam chest. This surface contains three passages, or *ports*, as they are called, the two outer, or *steam ports*,

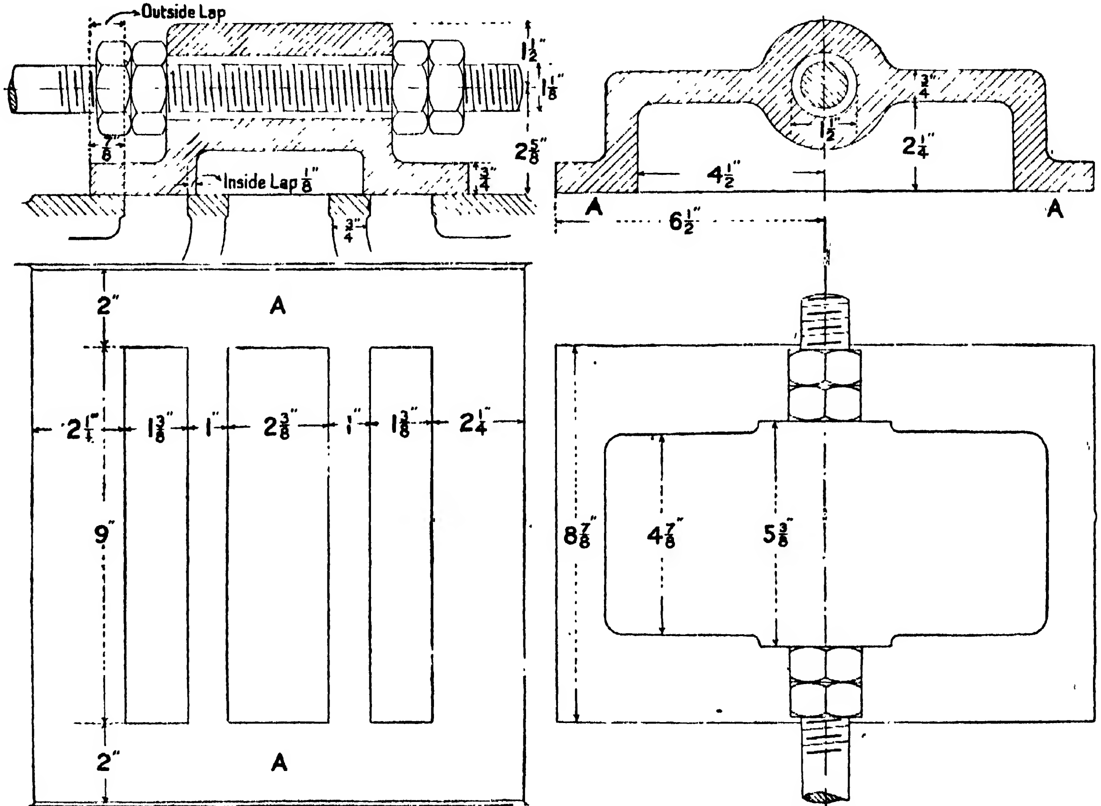


FIG. 232.—Slide Valves and Ports.

leading to the ends of the cylinder, whilst the inner, or *exhaust port*, simply allows the steam to escape either to the condenser or to the atmosphere.

When the valve is placed in its mid-position, as in Fig. 232, the face of the valve covers the two openings, or steam ports, and the exhaust is covered by the hollow part of the valve.

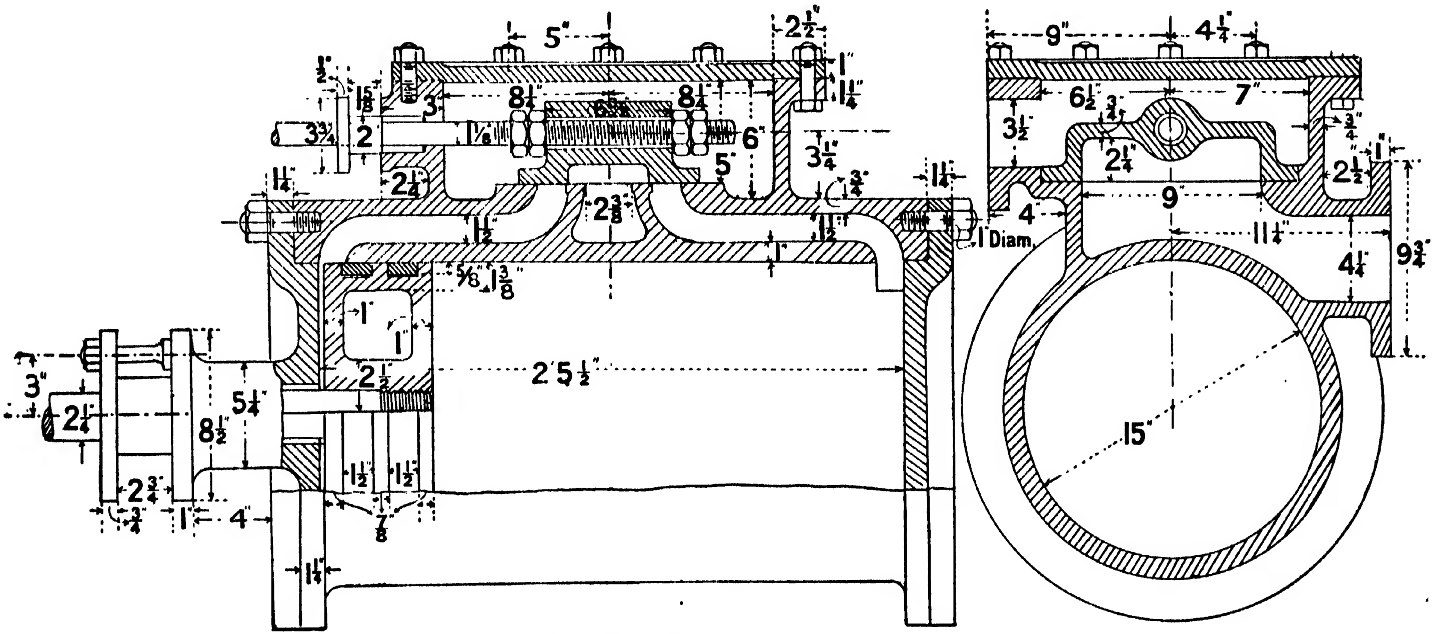


FIG. 233.—Cylinder and Slide Valve.

Example. Fig. 233 shows a sectional elevation of the cylinder, piston, valve, and valve-box, of a horizontal engine. Draw, $\frac{1}{4}$ full size, and complete the views shown. The details of the slide valve are given in Fig. 232.

Lap. It will be noticed that the edge of the valve is not coincident with the edges of the steam ports, but projects some distance beyond. This prolongation, or projection, is called the **outside lap** of the valve, or simply the **lap.** In a simple form of valve, such as that referred to, the lap is usually the same on both sides of the valve.

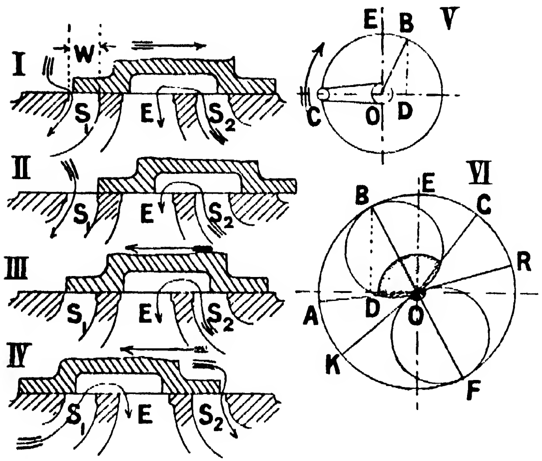


Fig. 234.

In vertical engines, the lap on the upper edge of the valve is frequently slightly greater than that on the lower edge.

The distance that the inner edge of the valve covers the inner edge of the port is called the inside lap of the valve, or simply the **inside lap.**

The object in providing outside lap is to ensure expansive working. Thus, if there is no outside lap, then the valve remains open, and steam is admitted during the whole stroke of the piston. With lap, the steam is only allowed to enter the cylinder during a part of the stroke, and the pressure is furnished by the expansion of the steam.

The object of inside lap is to ensure that the exhaust closes before the end of the stroke. In this manner, a certain volume of steam, which remains in the cylinder, is compressed by the piston, and produces what is called **cushioning.**

Lead of a valve. When the piston is at one end of the stroke, the distance that the slide valve has uncovered the edge of the steam port is called the *lead*. Thus, in Fig. 234, at **I,** in which the valve is moving in the direction of the arrow, the valve has moved from its mid-position a distance equal to the lap, together with a distance of $\frac{3}{16}''$, or distance from mid-position $= \frac{7}{8}'' + \frac{3}{16}'' = 1\frac{1}{16}''$. Draw, as at **V**, the crank **OC** in a horizontal position; make **OD** = lap + lead and draw a perpendicular **DB.** Join **B** to **O,** then **OB** is the position of the eccentric crank. The eccentric is thus 90° + the angle **EOB** ahead of the crank **OC**; the angle **EOB** is called the **angle of advance.**

Successive positions of the slide valve are shown at **I ... IV** (Fig. 234).

At **I**, steam is entering the cylinder through the port **S_1**, the piston moving from left to right; the steam from the opposite end of the cylinder is escaping to the exhaust through the port **S_2**.

The edge of the valve may uncover the steam port to a distance 0·7**w** to 1**w**, where **w** is the width of the port.

At **II**, the valve is shown in the extreme position to the right. At **III**, the valve moving from right to left, as indicated by the arrow, just covers the port **S_1**; this point of the stroke is called **point of cut off.**

At **IV**, the port **S_2** is open an amount equal to the lead, the piston being at the extreme end of the cylinder. Steam is escaping to the exhaust through the port **S_1**.

Zeuner's valve diagram. The motion of the eccentric relative to the crank is made clear by the Zeuner diagram shown at **VI** (Fig. 234). This diagram is constructed as follows:—Draw a circle **CFAB**, its diameter being the **travel of the valve**, and set off the angle of advance, **EOB**, on the opposite side of the vertical as shown.

Produce **BO** to **F**, and on **OB** and **OF** as diameters describe two circles. With **O** as centre and radius equal to the *outside lap*, describe an arc of a circle. Join **O** to **D** the point of intersection, and produce to **A**. Then **A** is the position of the crank when admission of steam takes place. Similarly, **C** is the point at which the steam is shut off.

In a similar manner, with centre **O** and radius equal to *inside lap*, describe an arc of a circle. Joining **O** to the points of intersection and producing to cut the circle, determine two points **R** and **K**. At the former, the valve is just opening to exhaust, and therefore **R** is called **point of release.** At **K**, the value is just closing, and this is called the *point of compression.* The four points: **admission, cut off, release,** and **compression** may be clearly made out by drawing the diagram to scale.

Air pump valves. Air pump valves are made frequently of india-rubber. The material has to be prepared specially to resist the action of the mineral oil used for lubricating purposes.

Sheet metal is also used largely for the purpose. In this form the valves may be made very light, and they have the advantage that they are not affected by grease. Valves of this type are shown in Fig. 237.

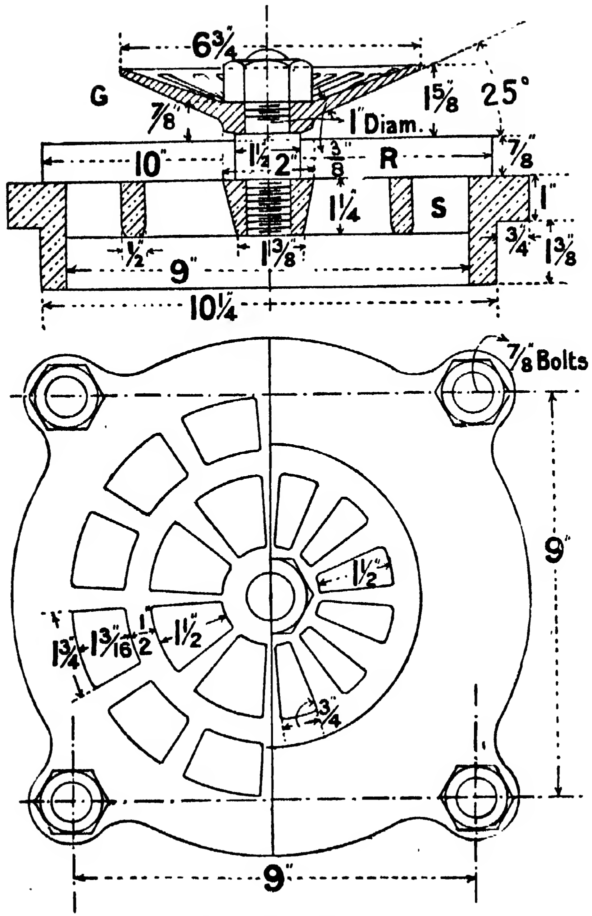


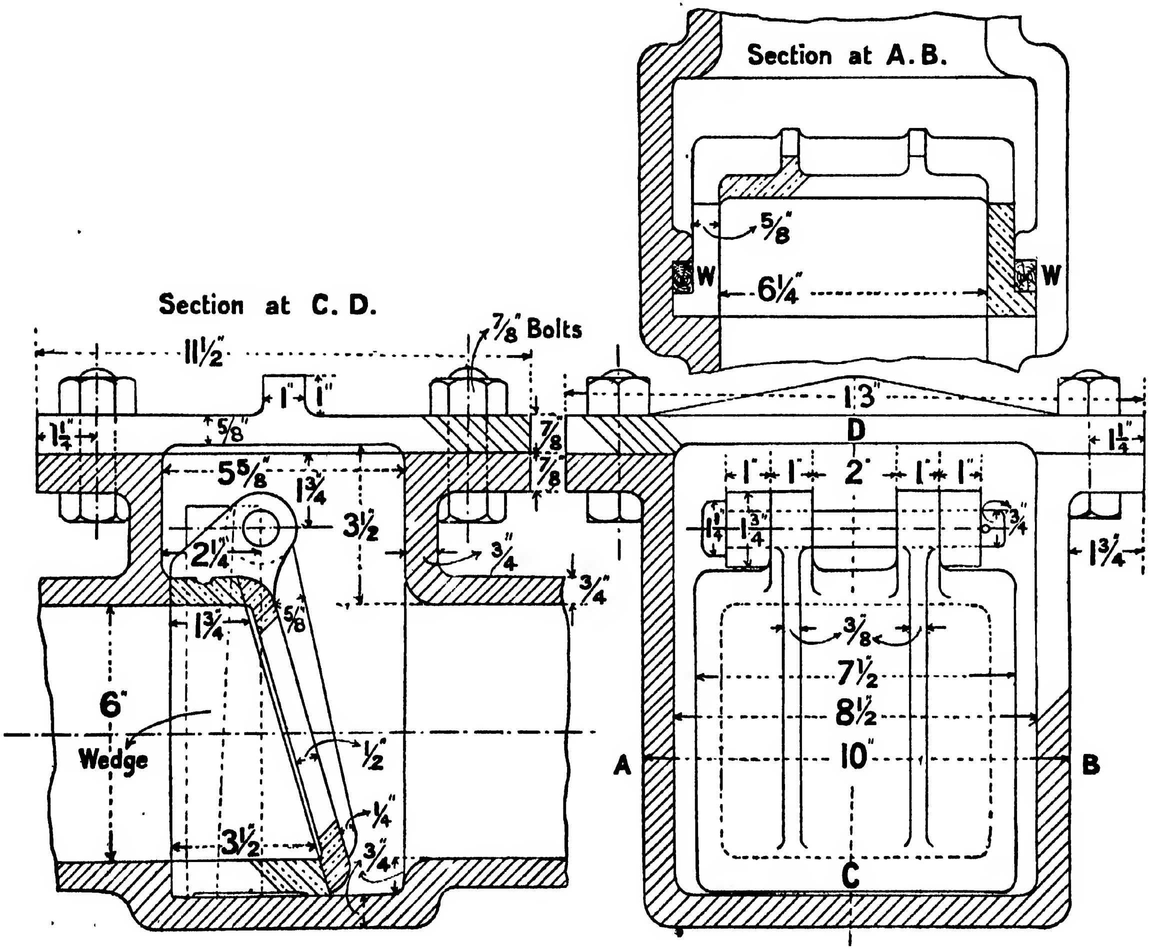
FIG. 235.—India-rubber Disc Valve.

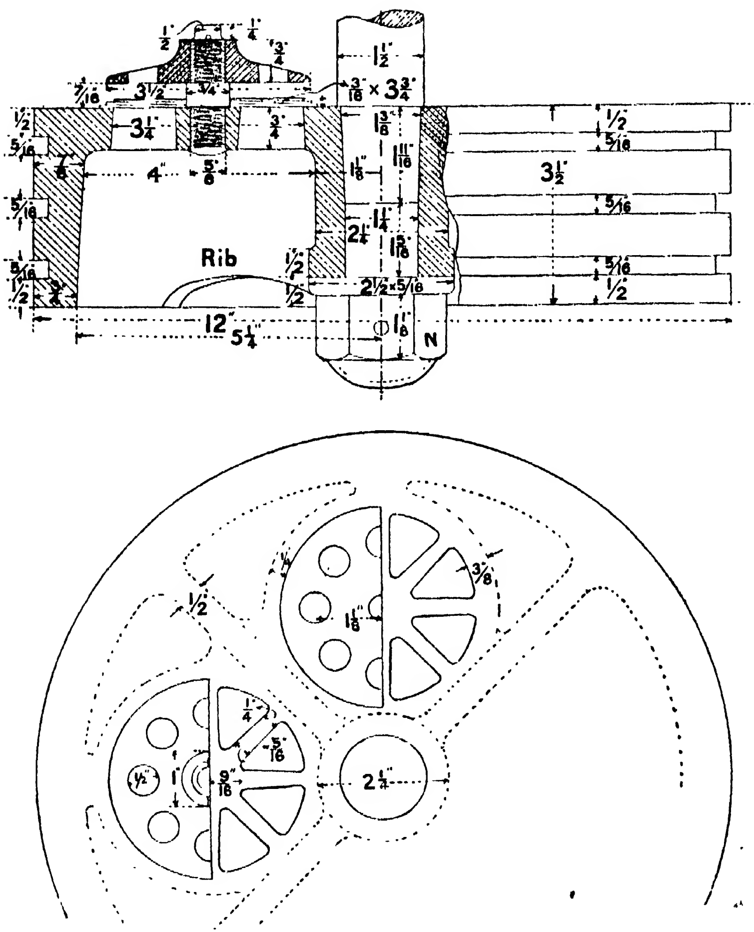
India-rubber disc valve. This form of valve is shown in Fig. 235. It consists of a flat cylindrical disc of india-rubber, **R**, resting on a perforated seating **S**. A perforated guard **G** will allow the india-rubber disc to move through a certain definite distance; thus the pressure of the fluid will cause the india-rubber to move against the guard. Any pressure in the return direction causes the disc to assume its former position and thus to close the opening. The grating ensures that the disc is not forced through the opening. Valves of this kind open and close quietly.

Example. Draw the two views of the india-rubber disc valve (Fig. 235). Scale half size.

Metal flap valve. This type may be a hinged valve as in Fig. 236. The valve is placed in a pipe as shown and will allow water or other fluid to pass in one direction, but will prevent effectually its return. The valve consists of a rectangular brass plate resting on a brass seating; the seating is held in position by wooden wedges **W**, **W**, (Fig. 236). The enlarged portion of the pipe, in which the valve works, is called a *valve box.* A cover is provided, as shown, to effect renewals or repairs.

Example. Draw the three views of a metal flap valve (Fig. 236). Scale half size.


Section at A. B.
W
6¼"
5/8"
W
Section at C. D.
11½"
7/8" Bolts
1" 1"
13"
D
1¼"
5/8"
7/8
7/8
5⅝"
1¾
3½"
2¼"
¾"
¾"
1" 1" 2" 1" 1"
1¼"
1¾"
¾"
1¼"
1¾"
1¾
5/8
3/8
7½
8½
6"
Wedge
½"
10"
A
B
¼"
3½"
¾"
C



Air pump bucket. In Fig. 237 is shown a sectional elevation and incomplete plan of the bucket used in Edward's air pump. There are four Kinghorn's valves, made of thin sheet metal. Those nearest the grating are perforated usually to allow any fluid that may enter between the surfaces to escape. The guard also is perforated for a like reason. The air pump rod is fastened to the bucket by means of a *box nut*, **N**, in which one end of the nut is closed to preserve the bolt from corrosion.

Example. Draw and complete the two views shown of an air pump bucket (Fig. 237). Scale half size.

Standard plug cock. Water or plug cocks are used to open or close a pipe for the passage of water or other fluid. The valve is made of a taper form—the frustum of a cone—and fits accurately into a hollow conical casing. The passage for water or other fluid is formed through the plug by rotating it. When the holes in the plug are in contact with the metal surfaces of the casing the cock is closed. Four views are shown in Fig. 238. Adjustment is provided by means of the gland bolts and the screw **S** at the base.

Example. Draw, half size, the **four** views of a plug cock (Fig. 238).

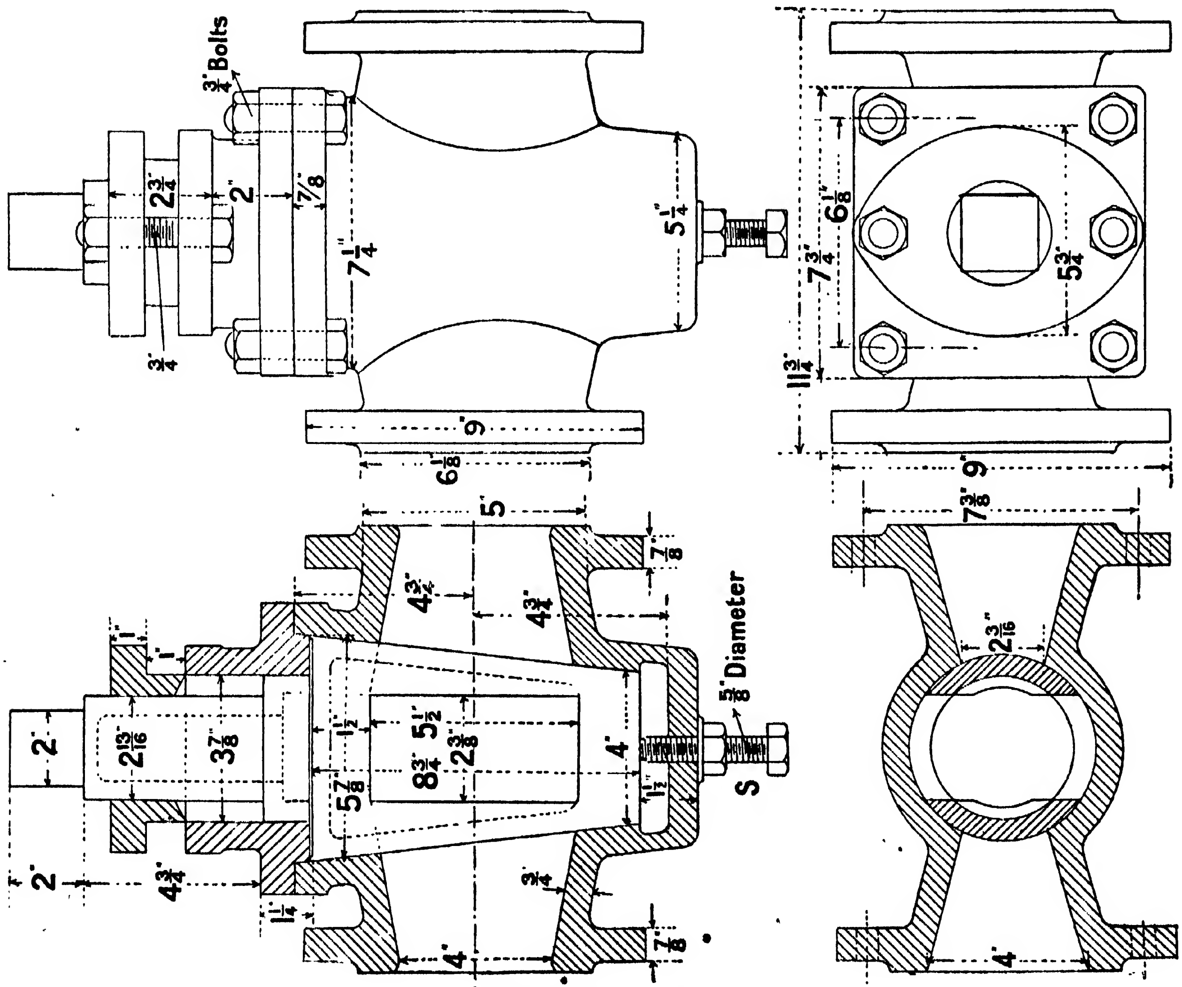
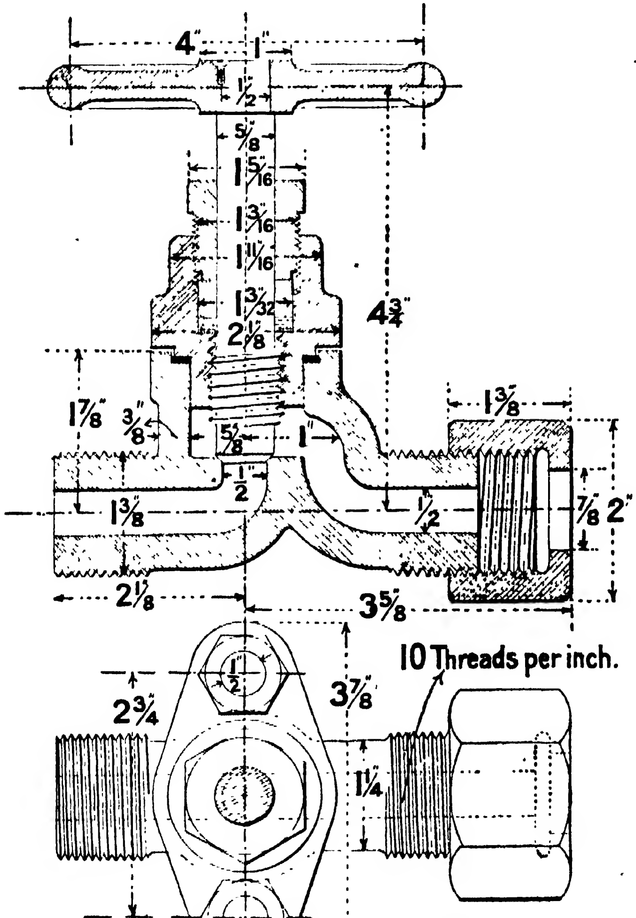
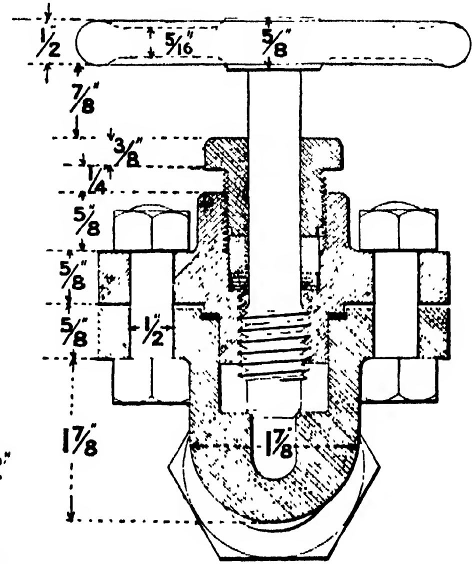


FIG. 238.—Plug Cock.





Stop valve for hydraulic pipes. Three views of a stop valve for hydraulic pipes are shown in Fig. 239.

Example. Draw, full size, the three views of a stop valve (Fig. 239).

FIG. 239.—Stop Valve.

Ramsbottom double safety valve. Fig. 240 shows a sectional elevation and plan of a safety valve; the two disc valves are each 2″ diameter and are placed $5\frac{1}{2}$″ apart. The valve faces are made flat instead of conical—the width of each face being about $\frac{1}{8}$″. The valves are held down by a helical spring made of $\frac{3}{16}$″ square steel. The pressure on the valves is regulated by the nut **N**. By means of the lever **L** either one or the other of the valves can be relieved to ensure that no jamming occurs.

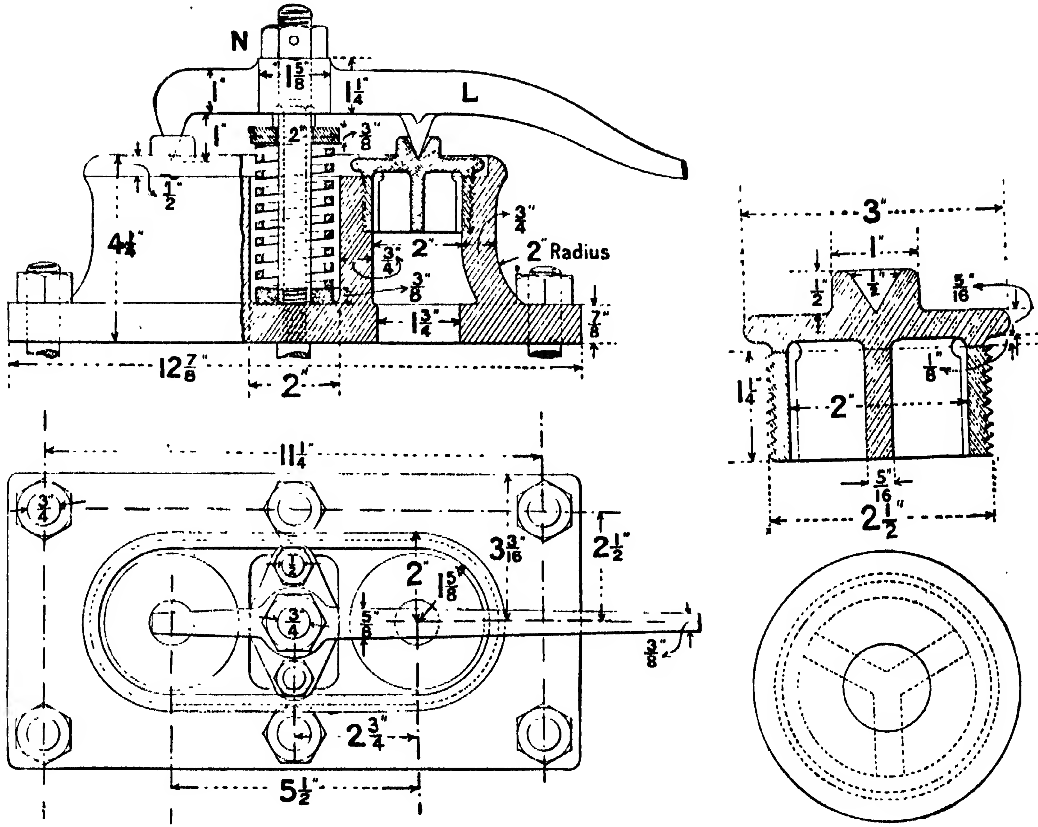
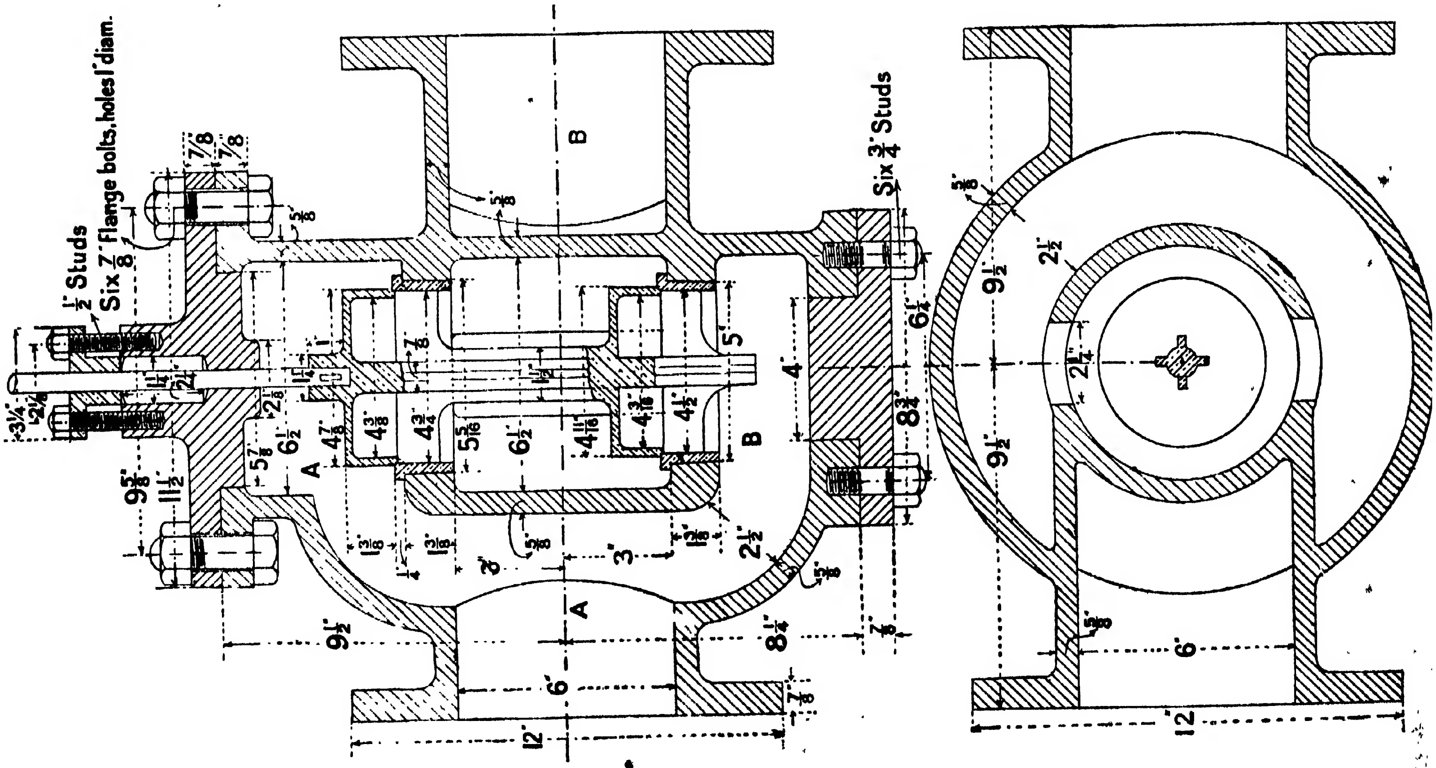


Fig. 240. Safety Valve.

Example. Draw sectional elevation, plan, and end view of safety valve (Fig. 240). Spring, $1\frac{3}{4}$″ outside diameter; made of $\frac{3}{16}$″ square steel, pitch of coils $\frac{3}{8}$″. Scale half size.

Regulating or throttle valve. This form of valve (Fig. 241) is also called an *equilibrium valve.* There are two valves either of equal or nearly equal size. The downward pressure of the steam on one valve is balanced by the upward pressure on the other.

Example. Draw the two views of the throttle valve (Fig. 241). Make any necessary corrections in the two views. Scale half size.



EXERCISES. XIV

1. Give sketches showing the construction of a conical metal lift or puppet valve and seating Show how the valve is guided in its movement and how the height of the lift is limited.

2. Sketch a slide valve in mid-position to the following dimensions: Exhaust port, 3″ wide; bars, 1″ wide; steam ports, 2″ wide; outside lap, $1\frac{1}{2}$″. Sketch also the same valve at the commencement of the stroke with $\frac{1}{8}$″ lead.

3. Show, by sketches, the construction of a slide valve for a steam engine. Show how the valve rod is secured to the valve, mentioning the conditions to be observed in this part of the design.

4. What should be the lift of each of the valves of the pump (Fig. 246) so that the sectional area of the water passages may not be obstructed?

5. With the aid of sketches, describe the construction of some kind of screw-down stop valve in which the seating is made of soft metal which is arranged to be readily renewable.

6. With the aid of sketches, describe how the valves of the air pump of a condensing steam engine are fitted (1) when made of india-rubber, (2) when made of thin flexible metal. Compare the relative merits of the two.

7. Give sketches showing the construction of any form of turn-cock for shutting off water or steam. When, after use, it leaks, point out where the ill fit generally occurs, and describe how you would refit it.

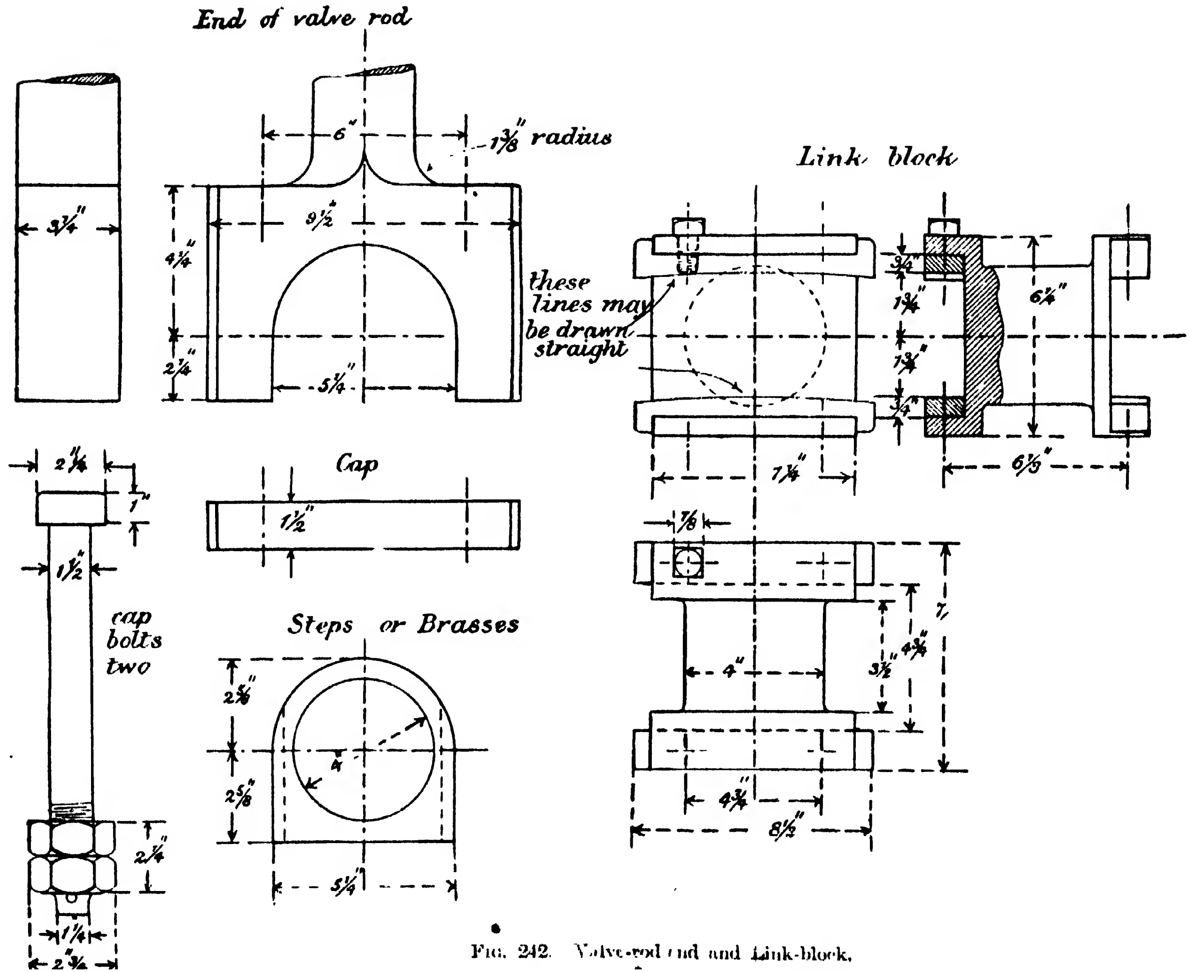


FIG. 242. Valve-rod end and Link-block.

8. Valve-rod-end and link-block. The diagram (Fig. 242) shows the details of the end of a valve rod, which is to be coupled to a block also shown, designed to fit a double bar link. Do not draw the parts separated from one another as in the diagram, but draw all the parts in their proper relative position. Scale half size. [B.E.]

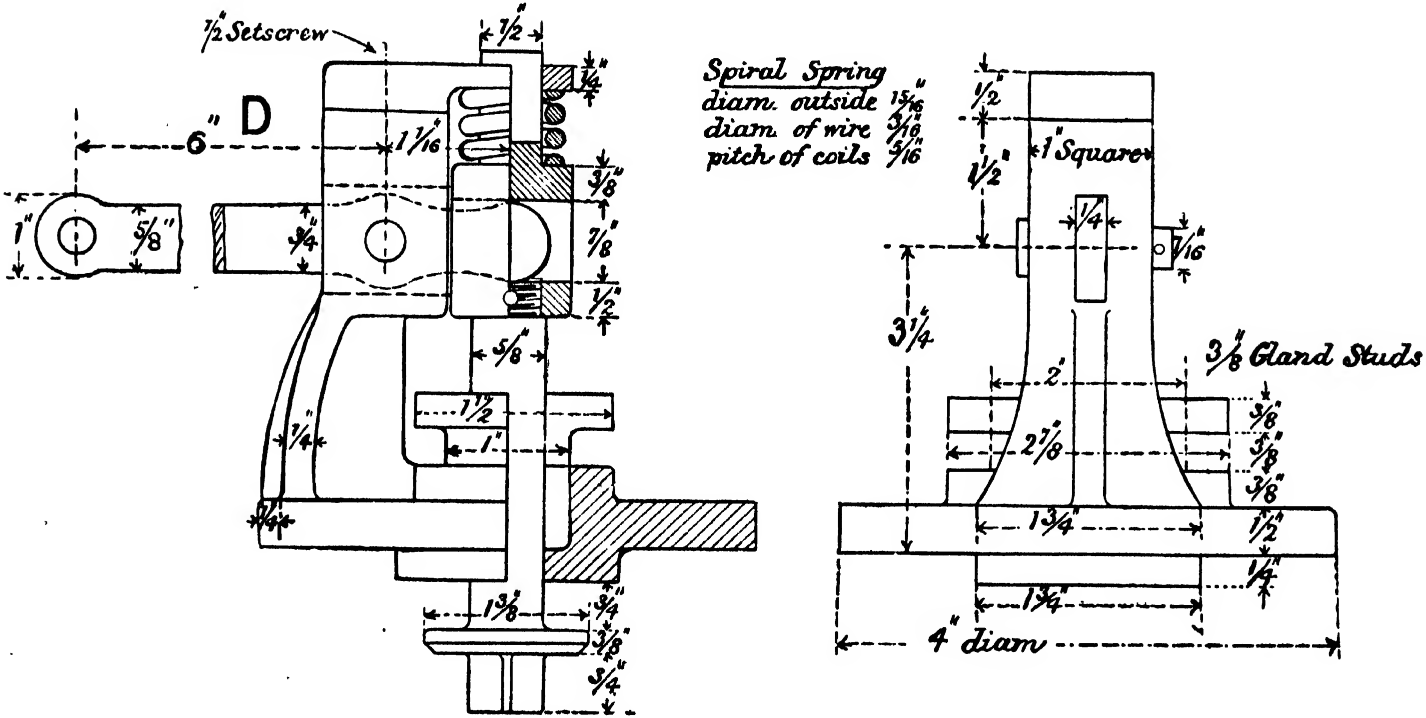


FIG. 243. -Spring-loaded Safety Valve.

9. Draw, full size, the sectional elevation and end view of the spring-loaded safety valve shown (Fig. 243). Also draw a plan projected from D. [B.E.]

10. Draw, half size, the two views of the slide valve for a steam engine (Fig. 244).

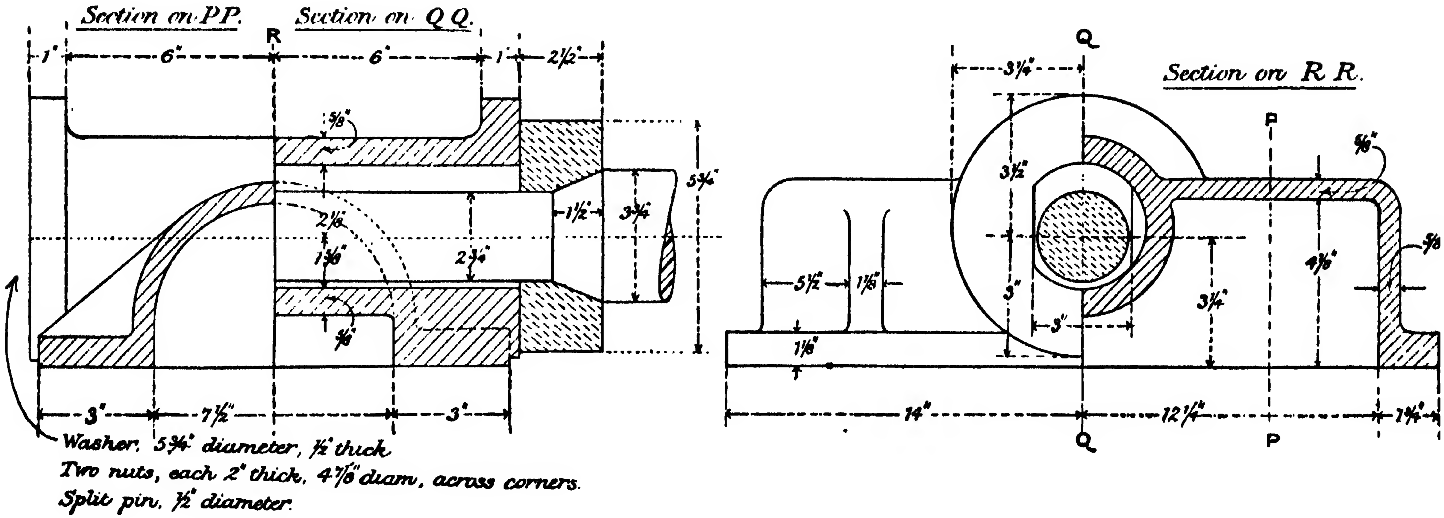


FIG. 244.—Slide Valve.

11. Two sectional views of a steam engine cylinder are given in Fig. 245. Complete the two views shown. Scale $\frac{1}{4}$. Insert some suitable form of valve and piston.

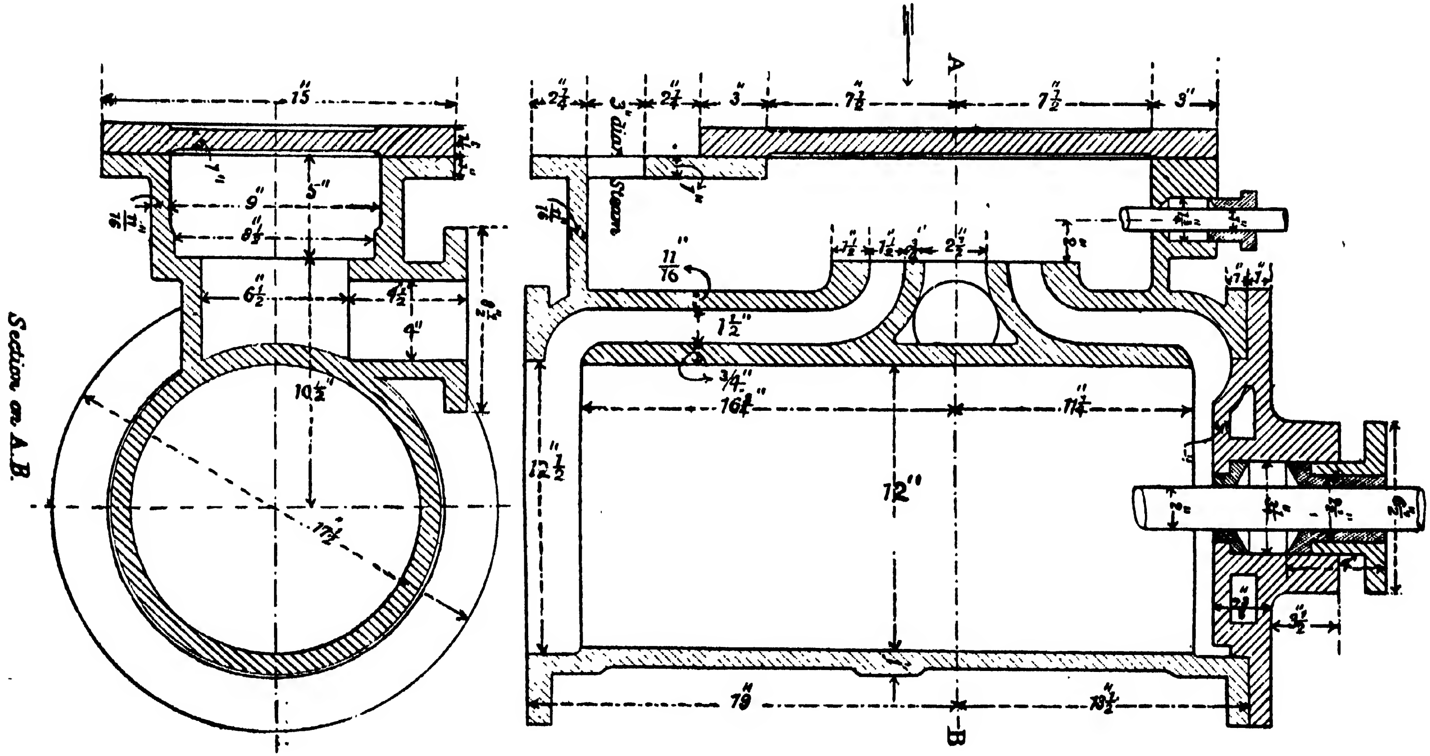


Fig. 245.—Steam Engine Cylinder.

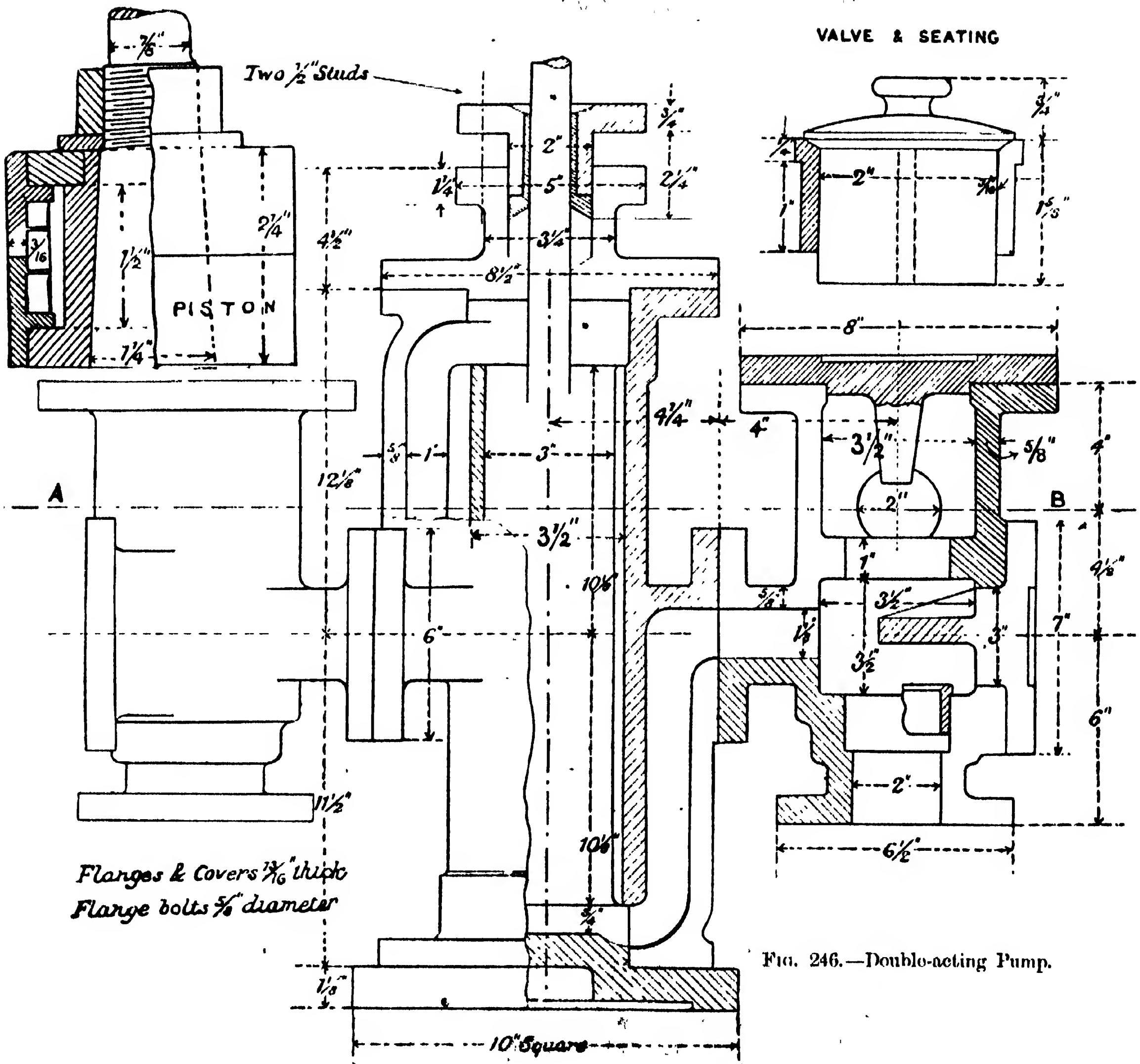


Fig. 246.—Double-acting Pump.

12. Draw and complete the sectional elevation and plan of a double-acting pump (Fig. 246) showing the valves and piston placed in position. Scale $\frac{1}{4}$. [B.E.]

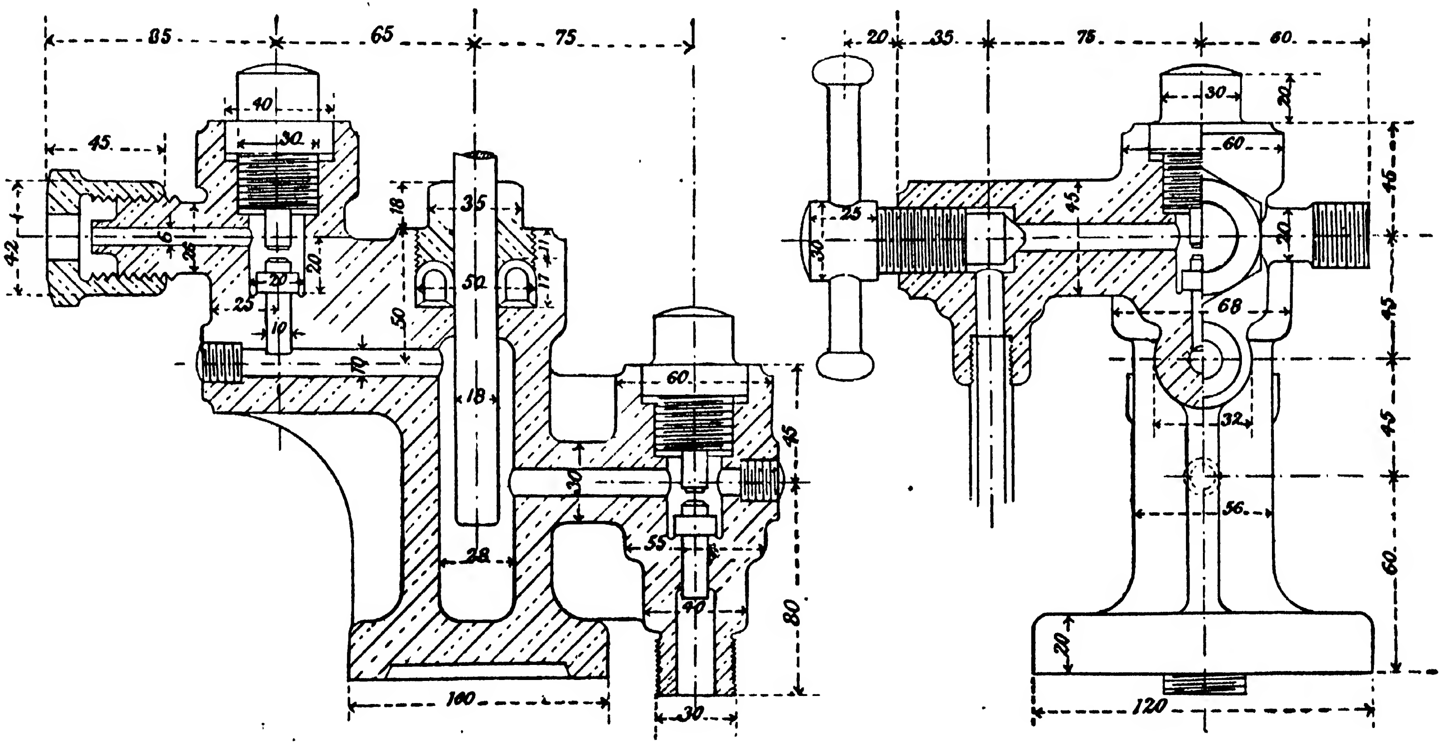
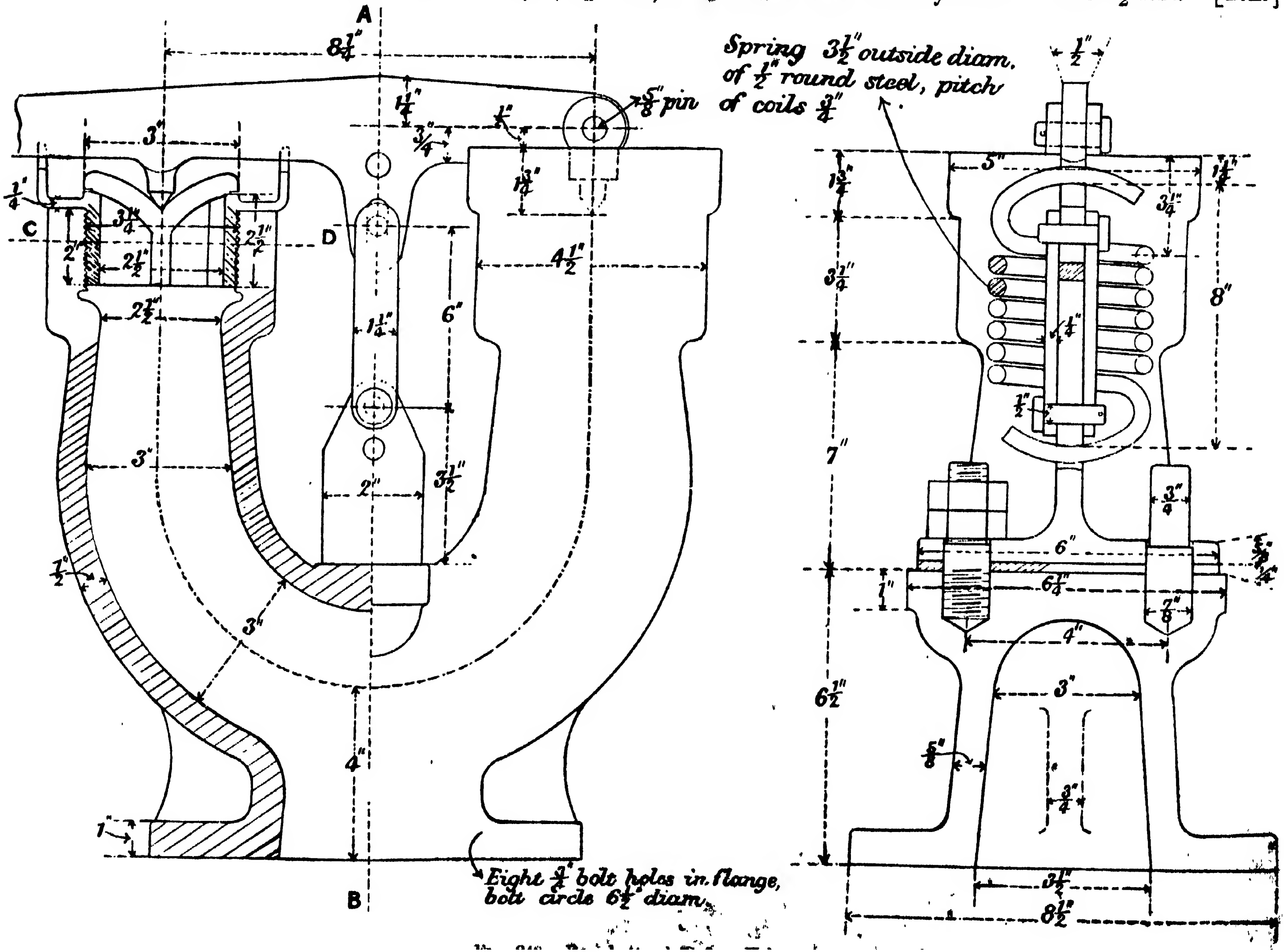


FIG. 247.—Force Pump.

The dimensions are given in millimetres.

13. Draw the two views shown (Fig. 247) of a pump for forcing water. Scale full size. [B.E.]

14. Draw and complete the two views shown (Fig. 248) of a Ramsbottom's safety valve. Scale ½ size. [B.E.]



CHAPTER XV.

MATERIALS.

It is only possible in these pages to give brief notes of a few of the more important materials used by engineers. For more detailed information the reader is referred to larger books dealing exclusively with the subject.

Iron. Using the term in its general sense to include cast iron, wrought iron, and steel, iron is chiefly obtained from *iron ore*. This ore consists of iron in combination with oxygen and carbonic acid, the compound being mixed with earthy matters, such as clay, etc.

The chief characteristics of the three varieties of iron may be said roughly to depend on the amount of carbon present. Thus *cast iron*, a compound of iron and 2 to 5 per cent. carbon, is easily melted and can be run into suitable moulds. The material is brittle; and the surfaces formed by breaking it are of a crystalline texture. *Wrought iron* is either pure iron or iron containing a very slight amount of carbon; it is *fibrous* and ductile and can be welded; it is used for shafts, bolts, etc. It may be magnetised rapidly and very quickly loses its magnetism; it is therefore used for making electro magnets.

Steel. The materials included under the general term steel vary from *mild steel*, a mixture of pure iron and about $\frac{1}{5}$ per cent. carbon and closely resembling wrought-iron, to *tool steel*, consisting of iron with 1 to 1·5 per cent. carbon. Tool steel, when made hot and suddenly cooled, becomes very hard. Its hardness may be removed partially by reheating and by the process known as *tempering* described on p. 227. When made hot and allowed to cool slowly steel remains soft.

Steel of this kind can not only be tempered but can also be permanently magnetised. Mild steel, containing less than 0·5 per cent. of carbon, cannot be tempered.

Between the extremes referred to there are a large number of varieties of steel.

The three metals described are of great importance to an engineer, and it is necessary to enter into more detailed explanation.

Cast iron.—The materials included under this general term vary to a great extent both in appearance and strength. Cast iron is obtained from iron ore *by smelting*. During this process a flux—usually consisting of lime—is added. This flux serves the purpose not only of promoting the fusion of the ore, but in addition combines with some of the early matters to form a fusible glassy substance called slag. The metal in its molten state is run into a series of shallow grooves and is afterwards broken into lengths of two or three feet, known as *pig iron*. The material thus obtained contains from 2 to 5 per cent. carbon and many impurities, such as silicon, phosphorus, sulphur, and manganese, which may to a great extent be eliminated by repeated processes of remelting, the quality of the iron improving with each remelting up to roughly about the fourteenth time.

Moulds and patterns. Patterns made of wood or metal of the exact shapes of the objects required are used to obtain cast-iron objects. These patterns are embedded in foundry sand rammed tightly so that when the pattern is removed an exact shape is left in the sand. This is called the *mould*. Molten metal is poured into such a mould and allowed to cool—a process known as *founding* or *casting*. When sufficiently cooled the castings are removed from the sand and cleaned. This process is called *fettling*.

The great and uncertain stresses in the material, which may be induced during the process of cooling, constitute one of the great objections to its use, and its place is being taken rapidly either by wrought iron, mild, or cast steel. The contraction during the process of cooling varies from $\frac{1}{16}''$ to $\frac{1}{8}''$ per foot. The material is also liable to have what are called *blow holes*, formed by *gas bubbles*, beneath the surface, which obviously reduce the soundness and strength of an object.

The soundness of an object may be in many cases ensured by casting the object under pressure. This is effected usually by placing the mould in a vertical position with some additional metal called a *head* above it. The lighter impurities, dross, etc., together with air or gas bubbles, ascend into this part, which is afterwards cut off.

The different varieties of cast iron are designated by iron merchants usually by the numbers 1, 2, 3..., the higher numbers denoting the whiter and harder kinds, and the lower numbers the greyer or softer irons. The whiter kinds are hard and brittle, and are, therefore, not often used for castings, in which a considerable amount of stress is likely to occur, or which have to be subjected to extensive operations by workshop tools. These whiter kinds of cast iron are called *forge irons*, or *forge pigs*, and are used chiefly for conversion into wrought iron. In these whiter kinds the carbon is in chemical combination with the iron, but in the greyer varieties, known as *foundry irons*, or *foundry pigs*, only a small proportion of the carbon is in chemical combination, while the remainder exists in the free state, simply mixed with the iron.

Machine details and the frames of machines are made of cast iron frequently on account of the facility with which an object even of complicated form can be cast. For a similar reason, together with the comparatively great strength in compression of the material, columns and pillars are in many cases made of cast iron.

Malleable iron. The brittleness of small cast-iron objects may be removed partially by heating a casting to a bright red heat and keeping it for some time in contact with powdered red hematite, which consists chiefly of peroxide of iron. In this process the carbon is partially burnt out; the material is toughened and converted into what is called *malleable iron*, resembling to some extent wrought iron or steel.

Chilled castings. When molten metal is cooled rapidly in a mould, it is found that some of the free carbon disappears and white hard cast iron is formed. This property is utilised in cases where some particular portion of a casting is required to be made harder than the remainder, as, for example, the points of conical iron shells. In such cases the mould at the part requiring to be made harder than the rest usually consists of a thick block of cast iron. In this manner the casting in contact with the cast-iron block is cooled very rapidly and becomes extremely hard to a depth varying from about one-eighth to half an inch. The surface in contact with the molten metal is protected by a wash of loam.

Ultimate strength and safe stress. The ultimate or breaking strength of cast iron is usually taken to be from 40 to 45 tons per square inch in compression, and from $7\frac{1}{2}$ to 10 tons per square inch in tension—a ratio of about 6 to 1. The average shearing strength is about 12 tons per sq. in.

The material may be made to take complicated shapes by casting in suitable moulds. It is of the utmost importance that the cross-section shall be as uniform as possible; when this is not the case the thinner parts cool first, and, in consequence, initial and unknown stresses due to unequal contraction may exist in the metal. The magnitude of these is sometimes so great that fracture may occur either before the casting is removed from the mould or during the subsequent workshop processes. It is necessary in order to prevent this tendency to fracture that all sudden variations in thickness and sharp corners shall be avoided, and that the cross-section shall throughout be as uniform as possible.

In cast-iron girders this uniformity of thickness is to some extent ensured by taking working stresses in compression and tension to be as 4 to 1 instead of 6 to 1. This gives as the safe working stress 6 tons per sq. in. in compression and $1\frac{1}{2}$ tons in tension. The cross-section of a cast-iron girder is made usually of the same thickness throughout. When, as in Fig. 249, the upper flange is made thinner than the lower, then the web **W** is made taper as shown, the areas of the two flanges are as 4 to 1.

What are known as *stiffeners* are inserted sometimes at distances of about 4 feet along the length to ensure lateral strength. One of these is shown at **S** (Fig. 249).

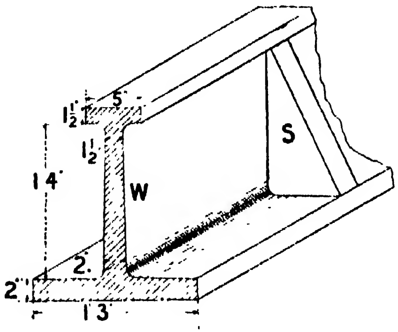


FIG. 249.—Cast-iron Girder.

Example. Draw cross-section and elevation of about 4 ft. of a cast-iron girder, 18 feet long. Scale ¼ (Fig. 249).

Wrought iron. Wrought iron is used for a variety of purposes including the making of shafts, bolts, nuts, etc. It is employed also for machine parts requiring strength and toughness. The material is obtained from cast iron by the processes of *refining*, *puddling*, *shingling*, and *rolling*, in which the greater part, or the whole, of the carbon and in addition many other constituents, such as phosphorus, etc., are eliminated.

When the metal is heated to a sufficiently high temperature in the presence of air, the oxygen of the air combines with the carbon forming an oxide of carbon, and when this is driven off the result is either pure, or nearly pure, iron. The mass of white hot metal is next worked under the hammer—an operation known as *shingling*—and finally passed through suitable rolls.

The fibrous character of the material and its tensile strength are found to depend upon the amount of rolling that the material receives during the process of formation into bar iron, and the following names used to designate various qualities of iron indicate primarily the amount of rolling the material has received. Thus, *Puddle bar* denotes iron which has only been rolled once; *Merchant bar* is formed from puddle bar by reheating and rolling. In both these cases the bars produced are of inferior quality and cannot be welded easily. By continuing the process, *Best bar* is prepared from Merchant bar.

Ductility. One of the most important properties of wrought iron is its *ductility*, or the amount of stretching that occurs before fracture of the material takes place. Thus, the best qualities of wrought iron will stretch from 20% to 25% in a length of 8″ before breaking with a contraction of area at fracture usually not less than 40 per cent.

Welding. Unlike cast iron, in which two separate pieces cannot be welded together, two surfaces of wrought iron can be hammered or pressed together when the metal is at a white heat (about 1600° F.) so as to form one piece of material. Also, it cannot be cast; at high temperature it assumes a pasty condition.

Ultimate strength and safe stress. The ultimate or greatest tensile strength of the material depends upon the quality of the iron; but ordinary good material will bear from 20 to 25 tons per sq. in. The greatest compressive strength varies from 16 to 20 tons per sq. in. The *safe working stress* is obtained by dividing these values by a number or factor called the *factor of safety*. Thus, if the factor of safety be 5, then the safe working stress is about 5 tons per sq. in. in tension and 4 tons in compression. In many cases, for convenience in calculation, 10,000 lbs. per sq. in. is used instead of the preceding value both for tension and compression, and 9,000 lbs. per sq. in. for shearing.

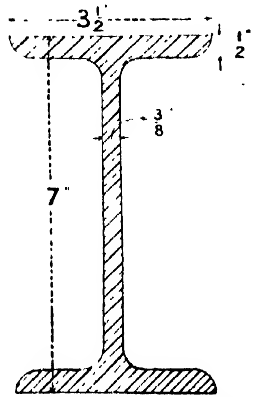


Fig. 250.—Rolled Iron Girder

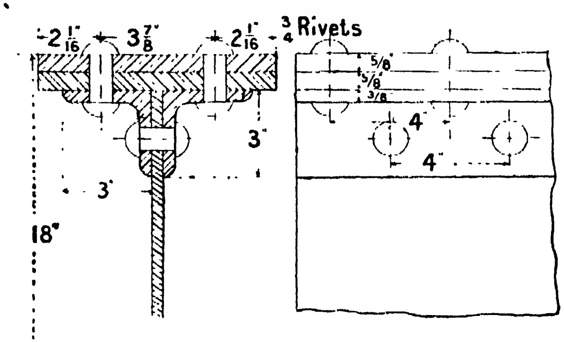


Fig. 251.—Plate Girder.

In the case of a wrought-iron girder the two flanges are usually equal in size (Fig. 250), and they are known as rolled iron girders in this form.

Example. Draw, half size, the cross-section of a rolled iron girder (Fig. 250). Also draw an elevation showing about 3 feet of the length.

In *plate girders* each flange consists of one, two, or more plates joined together by angle irons and rivets.

Example. Complete the two views shown in Fig. 251 making the elevation about 5 feet long. Scale ¼.

Effects produced by vibration. It is found that continual vibration tends to reduce the fibrous structure of wrought iron to a more or less crystalline material resembling cast iron. Shafts, etc., subjected to intermittent stresses are liable to fracture. The effects referred to, and known as *fatigue of materials*, are particularly noticeable in the fractured surfaces of crane and other chains which have been in use for some considerable time. The fibrous nature of the material may be restored by the process of *annealing*, in which the material is heated to a red heat and allowed to cool slowly.

Case hardening. The surfaces of wrought-iron and cast-iron objects, after they are finished by machine tools, may be hardened by heating the object to a red heat, then coating the surfaces to be hardened with powdered yellow prussiate of potash and quickly cooling in water. A similar result is obtained if, when the surfaces are heated, they are kept for some time in contact with carbonaceous substances, such as bone dust and cuttings of horn and leather. In this manner the outer surfaces acquire sufficient carbon to convert the surface for a comparatively small depth into steel. The depth to which the hardening extends depends on the time during which the process takes place.

Steel. Steel may be obtained either from cast iron by eliminating some of the carbon in it, or from wrought iron by adding carbon to it. The term steel includes materials which differ from each other very materially in many respects. These differences are produced chiefly by the varying percentages of carbon. The softer kinds containing 0·15 to 0·2 per cent. of carbon are used for bridge work, etc. Plates containing 0·25 to 0·3 per cent. are used largely for boiler plates, etc. The material resembles wrought iron in many respects, having the same facility of welding, equal toughness, and greater strength. Such steel cannot be *hardened*.

The harder qualities of steel contain more carbon, *i.e.* from 0·3 to 1·5 per cent. These have less toughness than the softer kinds, but much greater strength. The harder the steel is to be made the more carbon it should contain. Thus, *razor steel*, which becomes very hard and can be made to take a very keen edge, contains 1·5 per cent. carbon. *Tool steel*, which does not become so hard as the razor steel and can with care be welded, contains 1·2 per cent. carbon. When the steel contains 1 per cent. carbon it is called *chisel steel*. This steel admits of a good cutting edge, and the steel is also strong and tough. Steels containing less than 0·7 per cent. carbon are not used for tool making.

Manufacture of steel. Steel is made by what are known as the *Siemen's-Martin*, the *Bessemer*, and the *Cementation* processes. The cementation process is used for high carbon steel.

In the *Siemen's-Martin* process, the pig-iron is melted in a Siemen's gas furnace and the amount of carbon necessary is obtained by adding clean iron ore, scrap iron, etc., containing the requisite amount.

In the *Bessemer* process, the molten metal is poured into a *converter* and a blast of air forced through it. In this manner the oxygen of the air combines with and carries away the carbon in the form of carbon dioxide, and also results in the removal of many of the impurities, such as silicon, manganese, etc. Finally, sufficient cast iron of the whiter kind, called *spiegeleisen*, is added to give the exact amount of carbon required.

In the *Cementation* process, bars of pure wrought iron and broken charcoal are heated to a red heat and kept at that temperature for several days. The steel produced in this manner, after undergoing the hammering process, is known as *shear steel* and is used largely for tool making.

Mild steel is from 20 to 25 per cent. stronger than wrought iron, and, on account of the ease and facility with which it can be made, it is now used very largely for the various parts of engines, machine tools, etc. The steel used for boiler work has usually a tensile strength of from 27 to 30 tons per sq. in., with an elongation of about 20% in a length of 8″.

Nickel steel. Contains 7 to 30 per cent. of nickel. Tensile strength 40 to 45 tons per sq. in.

Hardening. One of the most important properties of steel is that known as *hardening*; *i.e.*, when a piece of the material is heated to a red heat and cooled by immersion in water, it becomes extremely hard and brittle. The degree of hardness depends upon the composition of the steel and the rapidity of the cooling.

Tempering. Closely associated with the hardening properties of steel is that known as tempering. Thus, a cutting tool of any kind—such as a chisel—would, if made red hot and slowly cooled, remain soft so as to be cut easily by a file. If made red hot and cooled quickly it becomes very hard. Its hardness may be reduced to any extent by the process of reheating. This process is called *tempering*.

A common practical method adopted for hardening tools is to make as much as may be necessary red hot and suddenly to cool the cutting edge by immersing it in water, afterwards allowing the temperature to increase by the conduction of heat from the other and thicker portions of the cutting tool until it reaches the necessary "temper" required. When this occurs the whole is cooled, to *fix*, or to *set* the tool.

One process of tempering may be illustrated by the method adopted to temper a fitter's chisel. The chisel is heated to a red heat, to a distance of say three or four inches from the cutting edge, and then partially cooled by immersing the cutting edge to a depth of about an inch in water. The cutting edge is

next rubbed on a piece of stone so that the colour of the film can be clearly seen. As the heat is conducted by the metal, the change in the colour of the film indicates roughly the degree of hardness. Thus, if when the colour changes from a pale yellow to a straw colour it is immersed in water, the temper would correspond to that used for razors and instruments of a similar kind. If the cooling be allowed to continue, the colour of the oxide would alter from straw to (*a*) brown, (*b*) purple, (*c*) blue. The first (*a*) would be suitable say for a chisel; the next (*b*) for wood turning and many other tools; and (*c*) for watch and other springs. Where elasticity is required the blue colour is also suitable for various tools, such as saws, etc., which require to be sharpened from time to time by files. Such tools are, however, frequently tempered to a suitable degree of hardness by heating and immersion in an oil bath. As already indicated, if the cooling be allowed to proceed slowly, then, when cold, the material can be operated upon by cutting tools as readily as wrought iron, a material which it closely resembles.

Cast steel. Steel is fusible and objects of it can be cast. But, unless the casting is made under pressure, the object is porous and contains numerous cavities.

Whitworth fluid compressed steel. Sir J. Whitworth has overcome this difficulty by subjecting the metal to great pressure whilst cooling in the mould. The steel produced by this process has a tensile strength from 30 to 40 tons per sq. in.

Lapping. When two surfaces of unequal hardness are pressed together, and one surface is made to slide over the other, friction between the two may result in the cutting or abrasion of the softer surface. The harder surface only suffers slightly, unless particles from other sources are embedded in the softer surface and act as cutting tools. In the operation of lapping, emery, or other very hard substance, is pressed into a softer one such as lead, the lead merely acting as a holder for the cutting material.

In a similar manner, in polishing and in cutting hard rock sections, diamond dust is pressed into the softer surface of an iron disc or wheel.

Friction. Friction may be used as a means of transmitting motion. Examples are to be found in belt and rope gearing, and in friction clutches of various kinds, etc. In all such cases the object usually aimed at is to make the frictional resistance as great as possible. These cases are considered in Chap. VI.

The object of a machine may be defined to be to control or to utilise energy for the purpose of doing useful work. As all machines are more or less imperfect, a part only and in some cases a considerable part of the available energy is wasted in various ways, *i.e.* in friction between the rubbing surfaces, friction of

the air, etc. It is of course of primary importance to diminish as far as possible the friction between two surfaces and in this manner to reduce the loss of energy to its smallest possible amount.

It is a matter of common experience that when two surfaces which may be apparently smooth are pressed together they cannot be moved without the application of force. This is necessary to overcome the roughness or unevenness of the surfaces in contact. The surfaces, although apparently smooth, may be assumed to consist of a large number of minute projections which exist on the surfaces, and the friction experienced is probably due to the interlocking which occurs when the surfaces are pressed together. Friction between two surfaces is therefore a force acting in the opposite direction to actual or possible motion, and may be either *sliding* or *rolling friction*. It is easy to verify that much less resistance is offered to rolling than to sliding friction. Thus, a heavy block of stone which may offer great resistance to a push or pull may probably be moved quite easily when placed upon rollers. It is for this reason that *friction wheels* are provided, that vehicles are furnished with wheels, and that ball bearings are used in cycles, etc.

Measurement of friction. When two surfaces are placed horizontally, the ratio between the force keeping the surfaces in contact and the force necessary to move one surface over the other is called the *coefficient of friction* for the two surfaces in contact; it is usually denoted by the letter μ. In many cases, the force referred to is simply that due to the weight of the moving body, and if F denote the force, W the weight of the moving body, and μ the coefficient of friction, then the relation is

$$\mathsf{F}=\mu\mathsf{W}.$$

It will be obvious that much will depend on the nature of the surfaces in contact. These may be what are termed smooth, rough, or any intermediate stage between these extremes. The coefficient of friction can only be expected to give, in any actual case, a fair approximation. The ordinary so-called laws of friction which are approximately true within certain limits are:

(1) friction is directly proportional to the pressure between the surfaces;
(2) is independent of the extent or area of the surfaces in contact;
(3) is independent of the velocity.

Friction may be reduced by making the surfaces in contact exceedingly hard and as smooth as possible. There are many reasons why such a process is not always practical, such as the great expense it would entail, etc. Hence, other and simpler methods are used. Thus, the surfaces in contact may be made as smooth as possible and of ample size to diminish the intensity of the pressure. Another method is to use

different metals for the two surfaces which work together, and by the use of various lubricants to prevent the surfaces actually coming into contact.

For example, the journal in a rotating shaft may be of steel or of wrought iron, while the bearing in which it rotates consists of some kind of alloy. This plan serves the double purpose that the loss by friction is reduced, and that the wear chiefly occurs in the small steps. Bushes, or brasses, of a bearing are of comparatively small size and when worn can be replaced easily. The use of a lubricant is to introduce a thin film between two smooth surfaces, and in this manner to prevent actual contact between them. If, however, the pressure between two surfaces is too great, the lubricant may be squeezed out and the two metals come into contact. When this occurs, what is called *seizing* takes place and the two metals adhere so closely that usually considerable force is necessary to effect a separation.

Copper. This material, easily recognised by its characteristic reddish colour, is of great importance to the engineer. It is malleable and ductile, not only at ordinary temperatures but also at a red heat, and therefore can be worked either hot or cold. It is largely used for pipes which require to be bent to shape when cold, also in firebox plates, etc., where its power of resisting heat is of great value. It is a good conductor of heat and electricity. The ultimate tensile strength of cast copper is about 10 tons per sq. in.

Alloys. What are known as *alloys* are used for a great variety of purposes, including the rubbing or wearing parts of *bushes*, *steps*, etc., of rotating pieces, for the sheathing plates for ships, for the tubes for locomotives, for boilers, for water cocks, for valves, and for hydraulic purposes generally. The material for casting in sand moulds must, when molten, be sufficiently liquid to be capable of sharply entering and registering faithfully the most minute details of the mould. In addition, brass castings have often to be subjected to hydraulic tests, and the castings must therefore be free from what are called "pinholes."

Alloys consist of varying proportions of copper, tin, zinc, etc. It is possible here only to give a brief list of the more important and to state fairly average values of the constituents. For more detailed information works dealing with this subject alone must be consulted.

Brass. The term *brass* is usually taken to apply to those alloys of which copper and zinc are the chief and essential constituents. The range is a wide one; *i.e.* copper 90 to 35 per cent. and zinc 10 to 65 per cent. Many of these alloys, as will be seen from the following list, receive somewhat fanciful names.

The composition of brass for ornamental work varies from 90 per cent. copper, 10 per cent. zinc to 80 per cent. copper, 20 per cent. zinc.

Brass containing 65 to 70 per cent. copper and 35 to 30 per cent. zinc is largely used for rolling into sheets, drawing into wire, and is also used for steps, valves, cocks, etc.

Zinc is of a bluish colour. It is a malleable and ductile material and forms a constituent of several forms of alloys. It is used in the process of galvanizing iron and also for a variety of other purposes.

Aluminium is a whitish metal which is malleable and ductile. It is extremely light compared with other metals. Its specific gravity is 2·6, or about $\frac{1}{3}$ that of iron and steel. Its tensile strength is low, varying from 6 to 14 tons per sq. in.

Muntz metal contains about 60 per cent. copper and 40 per cent. zinc; in some cases one per cent. of lead is added. It is used for the tubes of locomotives, the sheathing plates of ships, bolts, studs, etc. Plates of this kind do not corrode readily. The thin coating of zinc which forms on the surface prevents, too, to some extent, the attachment of barnacles Tensile strength about 20 tons per sq. in.

Naval brass has usually a composition of copper 70 per cent., zinc 29 per cent., tin 1 per cent. As its name implies, it is extensively used in marine work for bolts, spindles, nuts, etc.

Gun metal or bronze. Alloys in which copper and tin are the chief constituents are usually known as *gun metal* or *bronze*. The hardness of the metal depends upon and increases with the percentage of tin. Thus, a composition of 90 per cent. copper and 10 per cent. tin would correspond to a soft bronze, whilst 82 per cent. to 18 per cent. forms a hard bronze. In some cases a little zinc is added. Thus, the Admiralty specification for gun metal is 88 per cent. copper, 10 per cent. tin, and 2 per cent. zinc.

Phosphor bronze is an alloy consisting of copper and tin together with a small proportion of phosphorus. Unlike ordinary bronze, it can be remelted without deterioration of quality. Tensile strength 20 to 30 tons per sq. in.

Babbit's metal. This anti-friction metal is largely used for lining the bearing surfaces of cast iron, steel, or brass bushes. The composition varies from 5 per cent. copper, 86 per cent. tin, 9 per cent. antimony, to 9 per cent. copper, 82 per cent. tin, and 9 per cent. antimony. The friction in a rotating piece is reduced by its use, and it is therefore used for bearings, connecting rod ends, etc. The material is comparatively soft, and must be supported in shallow trough-shaped recesses (Fig. 210).

Delta metal. Is a brass alloy containing a proportion of iron, tensile strength 22 to 35 tons per sq. in. It can be worked hot or cold.

EXERCISES. XV.

1. State the characteristic properties of brass, cast iron, and wrought iron. Mention several examples of machine details in which the metal used is selected on account of the possession of certain of these properties. [B.E.]

2. What is the composition of the soft alloy used for bearings known as white metal? State the advantages due to its use, and show by sketches how it is attached to the brass or gun-metal steps of a bearing. [B.E.]

3. Name the material you would use in the construction of (*a*) a lathe bed; (*b*) the plunger of a water pump; (*c*) a steam boiler. In each case give reasons for your answers.

4. Give an instance in which some portion of a machine is case-hardened. Describe how the process of case-hardening is performed, and how the hardened surface is made accurate and smooth. [B.E.]

5. Describe the manufacture of malleable iron.

6. As an example of hardening and tempering, explain the process of making an ordinary chipping chisel,

7. Why are wrought-iron girders preferable to those made of cast iron? Sketch a section of a wrought-iron and also a cast-iron girder.

8. Give sketches showing two instances, differing as much as possible from one another in construction, where rollers are used in machines for the purpose of diminishing friction.

9. The flanges of a plate girder are $7'' \times \frac{1}{2}''$, the web $16'' \times \frac{3}{8}''$, angles $3'' \times 3'' \times \frac{1}{2}''$, rivets $\frac{3}{4}''$ diam., and $4''$ pitch.

Draw a cross-section and a portion of the elevation of the girder. Scale $\frac{1}{4}$.

MISCELLANEOUS EXERCISES XVI.

1. Elevation and plan of a bracket for supporting a pair of shafts at right angles to one another, connected by mitre wheels (Fig. 252). Draw the elevation and plan, the wheels and shaft being shown in place. Scale full size. [B.E.]

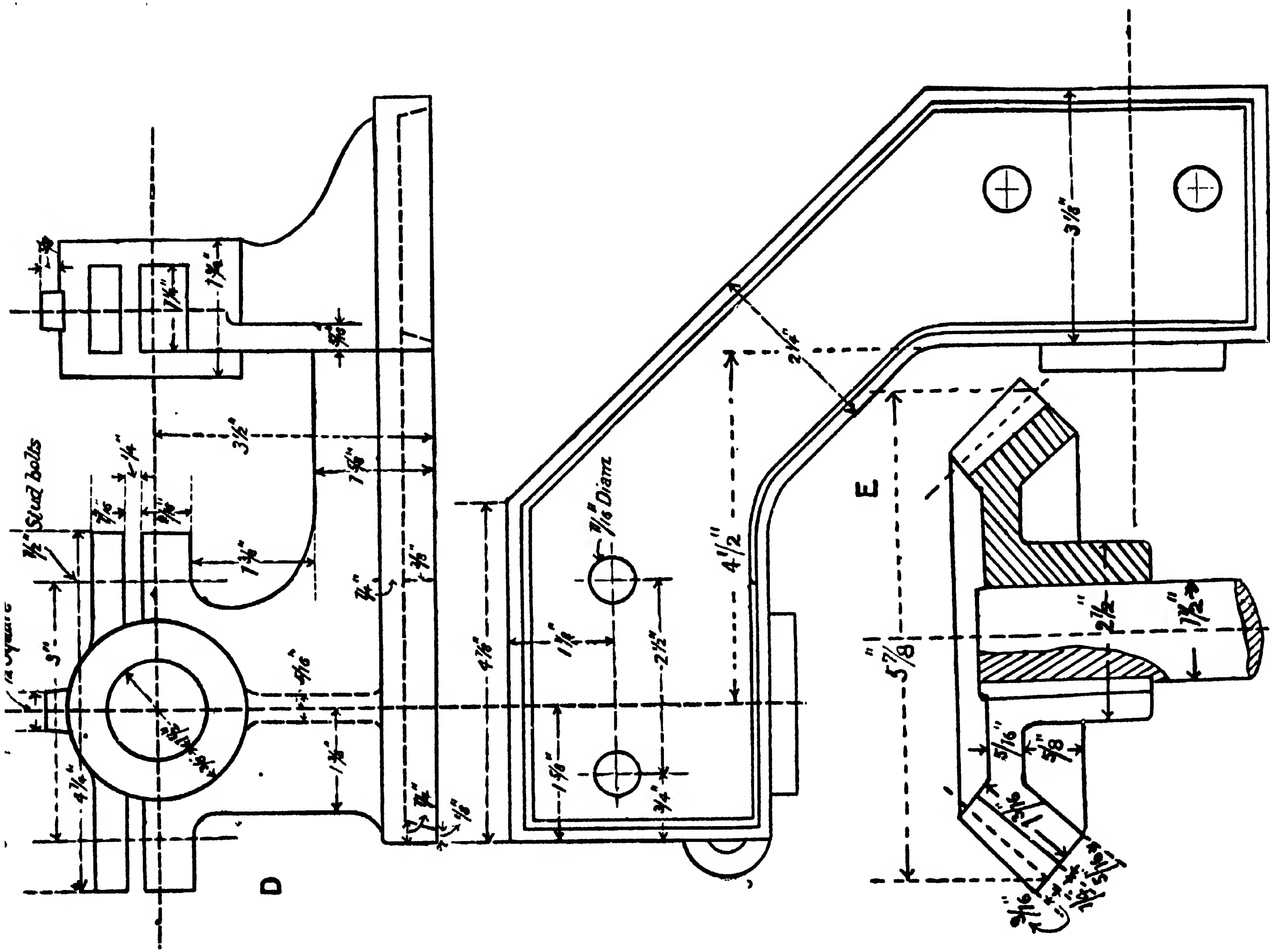


FIG. 252.—Bracket and Mitre Wheels.

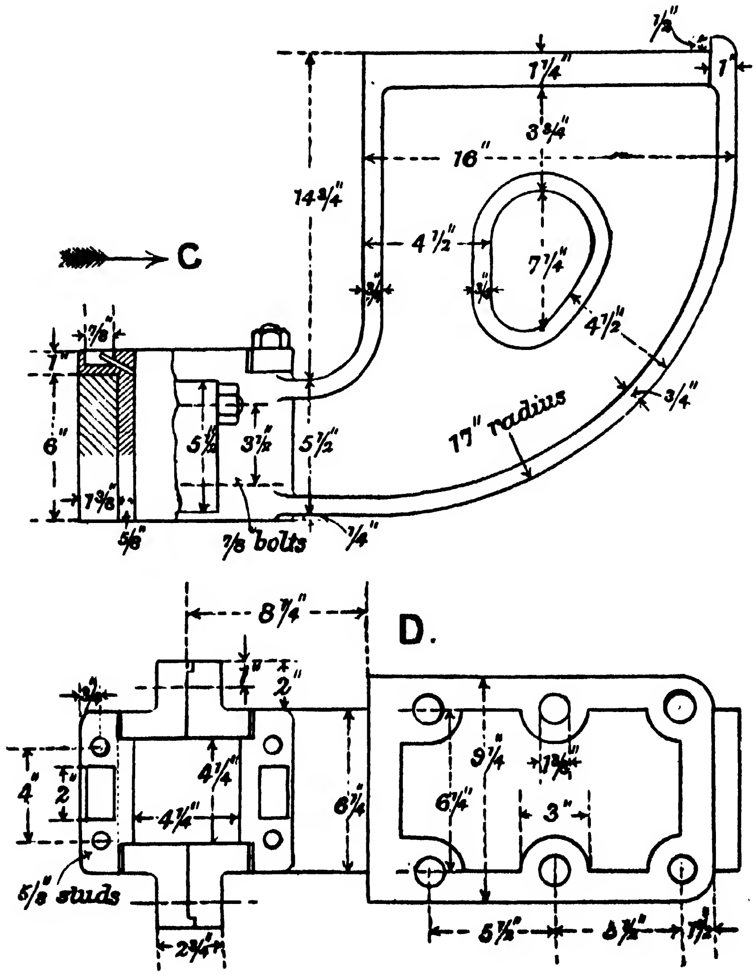


Fig. 253.—Guide Bracket for Valve-rod.

2. Guide bracket for a valve-rod. Draw and complete the views **C** and **D** (Fig. 253). Draw also a front elevation, projected from **C** as seen when looking in the direction of the arrow. Scale $\frac{3}{8}$ths. Make a tracing of the three views. [B.E.]

3. Hydraulic press. The diagram (Fig. 254) shows three views **D**, **E**, **F** of a press cylinder, and detached views of the cross-head plunger gland, etc. You are required to fit the parts together, and instead of drawing view **D** in outside elevation as shown, to draw a section taken through the centre of the cylinder; also, in place of view **E**, draw an outside view when looking in the same direction. Scale $\frac{1}{4}$. [**B.E.**]

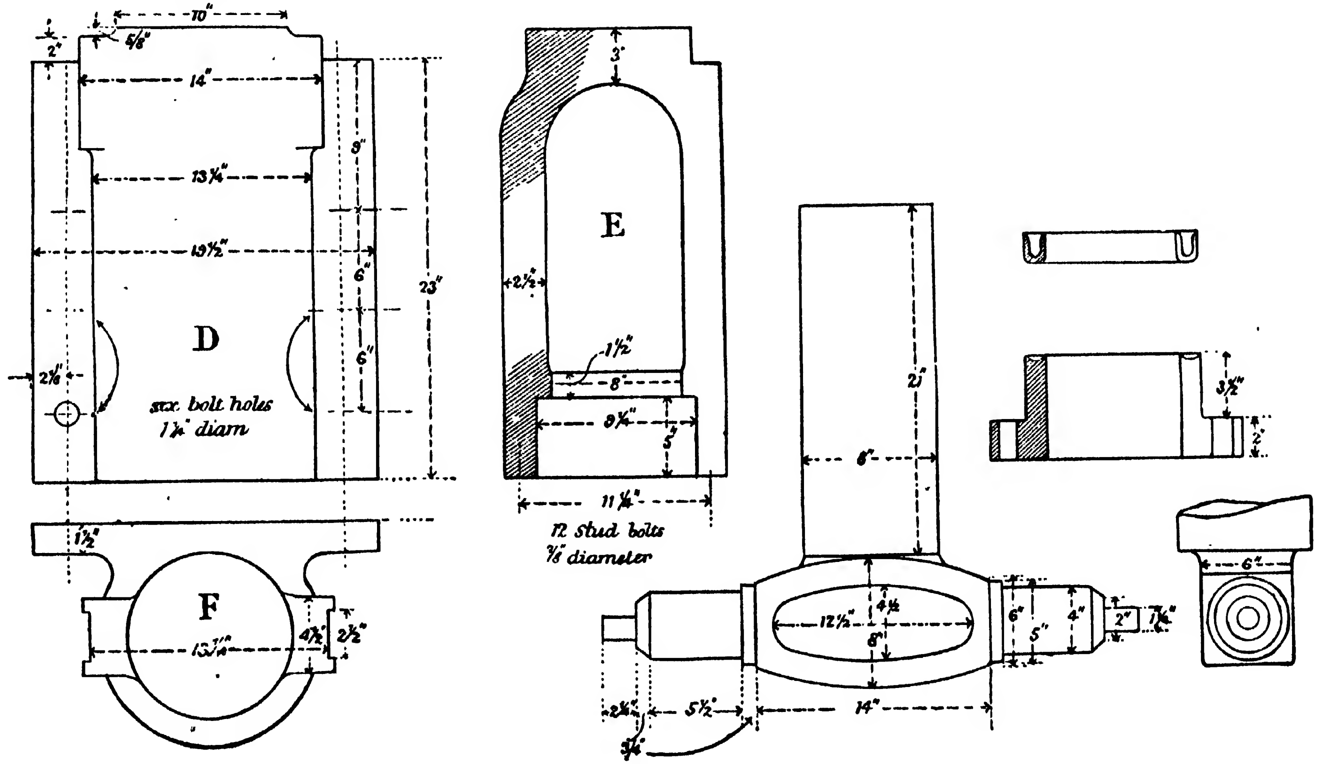


FIG. 254.—Hydraulic Press.

CHAPTER XVI.

ENGINEERING DRAWINGS.

It may be advisable to give a brief summary of the various points—many of which have already been referred to in the preceding pages—that must be attended to in order to produce a working drawing of good style and finish.

(*a*) In commencing a working drawing the centre lines should be drawn first. Care must be taken that the lines forming the drawing are equidistant from these lines.

(*b*) Although pencil lines may be set out of an indefinite length until the various dimensions are obtained, these must be made finally to terminate exactly at the points intended. This rule applies to all drawings either in pencil or ink.

(*c*) All the lines of a drawing should be firm and of uniform thickness. These lines, together with all the curves, should be drawn by the aid of instruments. In inking in, all lines should be perfectly black.

(*d*) Circles and curves touching lines should do so accurately; the point of contact should not be noticeable by the curve failing to touch the line.

(*e*) It is easier to draw a line to touch a curve than conversely. Hence, in inking in, the circles should be inserted first, then the straight lines, and finally any curves requiring the use of a guiding curve.

(*f*) Section lines should be equally spaced. If a flat wash of colour is used, the drawing board should be placed at a slight slope and the colour put on quite evenly beginning at the upper and working towards the lower parts of the drawing. Small pools of colour must not be left on any portion of the drawing.

(*g*) The letters and figures must be clear, well formed, and so arranged that all can be read without altering the position of the drawing. The arrowheads at the ends of dimension lines must terminate at the lines to which they refer.

It should be noticed that no written instructions can replace practice and experience; but attention to the preceding hints will tend to lessen some of the many failures which are so frequently noticeable in the work of those beginning the subject. Some of the more important points may be appreciated by comparing the two drawings of a piston (Fig. 255).

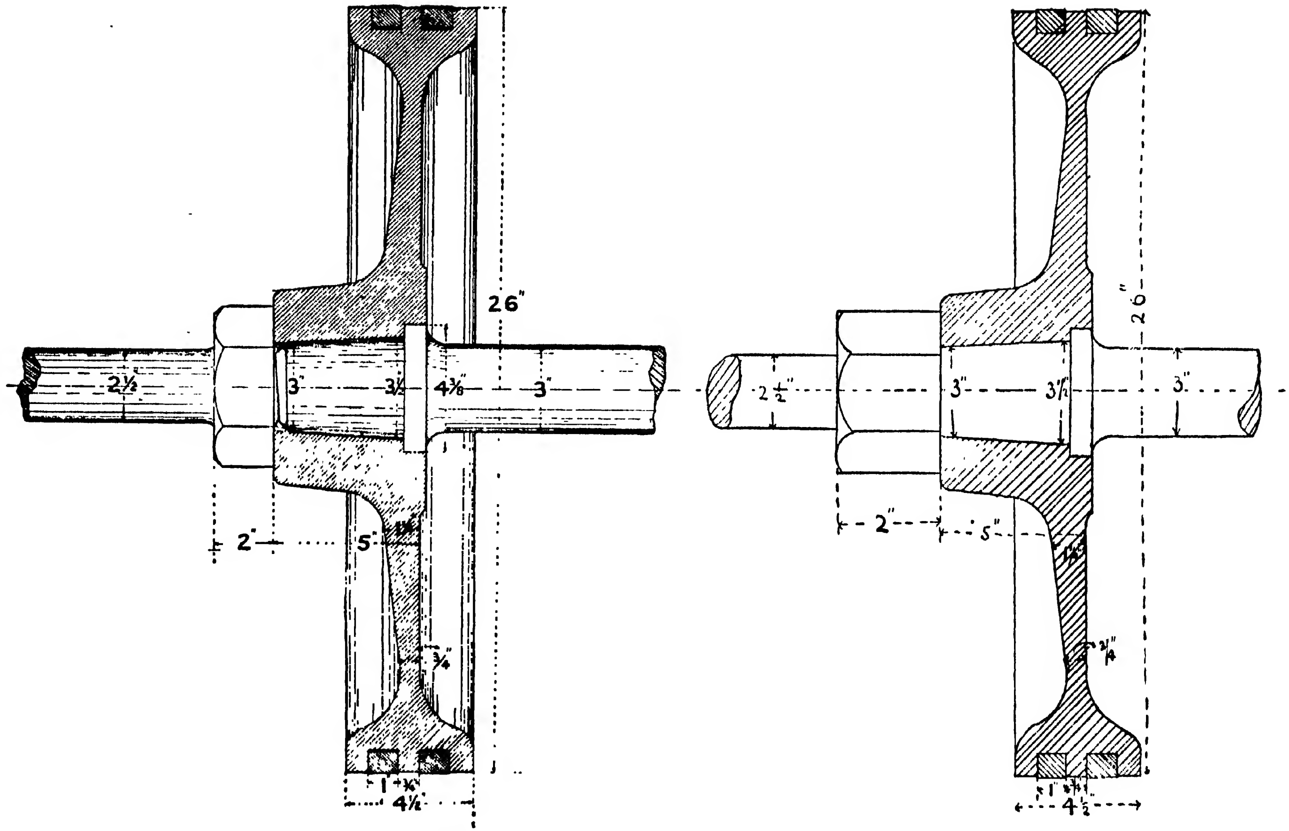


FIG. 255.—Contrast between a good and bad Drawing.

Use of squared paper. It will be noticed that when the area of cross-section of a bolt is given, or when it has been found by calculation, that its diameter together with the proportions of the bolt-head and nut can be obtained from tabulated values, such as those in Table V.

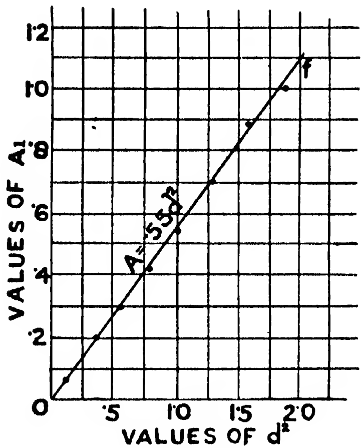


FIG. 256.

A simple relation between the diameter **d** and A_1, the sectional area at the bottom of the thread, for bolts in common use (say from $\frac{3}{8}''$ "to $1\frac{3}{8}''$), may be obtained as follows:

Plot on squared paper numerical values of d^2 and A_1. The line which passes evenly through the plotted points (Fig. 256) passes also through the origin **O**. The equation of the line may be written in the form

$$A_1 = cd^2 \ldots (1).$$

The value of the constant **c** is simply the slope of the line, *i.e.* its value may be obtained by substituting in (1) the values of A_1 and d^2 for any point in the line.

Thus, at **f**, the values of A_1 and d^2 are 1·1 and 2·0, respectively. Substituting these values in (1) we obtain

$$1{\cdot}1 = c \times 2;$$

$$\therefore \ c = \frac{1{\cdot}1}{2} = 0{\cdot}55.$$

Hence, $A_1 = 0{\cdot}55d^2$.

The sectional area of the bolt is $0{\cdot}7854d^2$, and as $0{\cdot}55 = \frac{7}{10} \times 0{\cdot}7854$ the relation is

$$A_1 = \tfrac{7}{10}A,$$

or the sectional area at the bottom of the thread $= \frac{7}{10}$ area of bolt.

$$d_1 = \sqrt{\tfrac{7}{10}}\,d;$$

$$\therefore \ d = 1\tfrac{1}{5}d_1,$$

or the diameter of the bolt $= 1\frac{1}{5}$ diam. at the bottom of the thread.

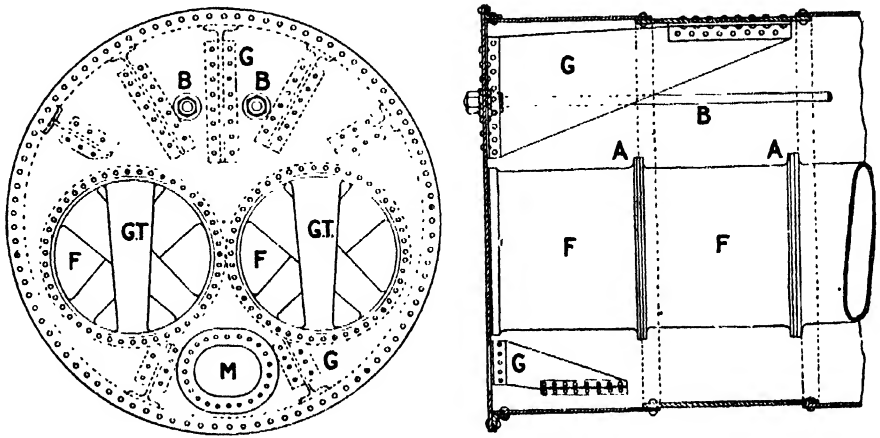
Thus, when d_1 the diameter at the bottom of the thread is known, it is only necessary to add $\frac{1}{8}d_1$ to obtain the diameter of the bolt.

The relation between d_1 and d could also be found by plotting values of d_1 and d from Table V.

The relations given on p. 51, connecting the diameter d with the width across the flats and the distance across the corners for nuts and bolt-heads, may be obtained by plotting the values given in Table V.

The relation between d, the diameter of a rivet, and t, the thickness of the plate, may be found by plotting numerical values of d and $\sqrt{t}$. The numerical value of c in the relation $d = c\sqrt{t}$ is then found as on p. 31 to be 1·2, and the relation is $d = 1{\cdot}2\sqrt{t}$.

The various linear relations connecting the size of the key and the diameter of the shaft, the proportions adopted for couplings, pipes, etc., may be obtained also by using squared paper.



Figs. 257, 258.—Lancashire Boiler.
A. Adamson ring; G.T. Galloway tubes; M. Manhole door.

Lancashire boiler. If the diameter is 7 ft. 6 in., pressure of steam 90 lb. per sq. in., safe stress 5 tons per sq. in., the thickness of the shell plates may be obtained by the formula on p. 38, and the size and pitch of the rivets as on pp. 31, 36, 37.

The pressure on the end plates is very great. Thus, if each flue (F) is 3 ft. diameter,

$$\text{Pressure on end plate} = \frac{\pi}{4}(7{\cdot}5^2 - 2 \times 3^2) \times 90 \times 144 \div 2240 = 173{\cdot}8 \text{ tons.}$$

The method of staying by gusset stays (G) and bar stays (B) is shown in Figs. 257, 258. Detail drawings on pp. 43, 57.

Water tubes. The effective heating surface is increased, a better circulation of the water in the boiler is ensured, and the strength of the furnace tubes is increased, by **tapered** or parallel water tubes. The tapered form, or **Galloway's tubes**, may be flanged at each end as is shown in Fig. 259, the hole at the upper end being made large enough to allow the lower flange to pass through. The tubes may be welded into the flues; this arrangement has the advantage that there is less fear of leakage at the joint, or of overheating at the riveted joints.

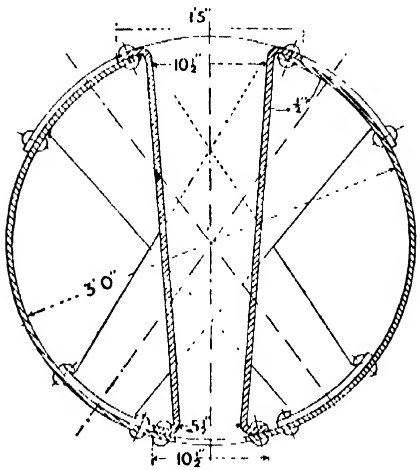


FIG. 259.—Galloway's Tubes.

The dimensions adopted are as follows :—

Up to 2 ft. long,	diameters of ends	8 in.	and	4	in.
Over 2 ft. up to 2 ft. 3 in.	,, ,,	9 in.	,,	4½	in.
Above 2 ft. 3 in.	,, ,,	10½ in.	,,	5½	in.

Furnace tubes. These are invariably of circular section, and are either plain or corrugated tubes of comparatively short lengths connected by one of the joints, or strengthening rings shown in Figs. 60, 61, 62. The object of these rings is to strengthen the tubes, allow for expansion and contraction and prevent collapse under external pressure.

The formula $PD = 2\,ft.$ (p. 38) for a thin tube under internal pressure can be used only for a tube subjected to *external* pressure when the tube remains *always* of a circular form in cross-section; hence other rules or formulæ are used as follows :—

(*a*) **Fairbairn's Rule.** $$P = \frac{806300t^{2\cdot19}}{L \times D},$$

P = collapsing pressure lb. per sq. in.; L = length in feet; t = thickness in inches; and D = internal diameter in inches.

This rule is based on the assumption that the strength of a tube varies inversely as its length, an assumption which is not strictly correct. The collapsing pressure given by it is found to be too great for short tubes and too small for long. Hence, other rules are used, such as :—

(*b*) $p = \dfrac{46550t^{2\cdot19}}{D \times \sqrt{L}}$. (*c*) $p = \dfrac{90000t^2}{(L+1)D}$ (Board of Trade). (*d*) $p = \dfrac{9000t}{D}$.

In any case, the safe or working pressure p found from (*b*) and (*c*) must not exceed that given by (*d*).

Ex. 1. Find the collapsing and safe pressure for a furnace tube 3 ft. diameter, thickness $\frac{3}{8}$ in., 3 ft. 6 in. long (between the rings). Let P denote the collapsing and p the safe pressure.

$$\mathrm{P}=\frac{806300\times(0\cdot375)^{2\cdot19}}{3\cdot5\times36}=746\cdot7 \text{ lb.}$$

From (*b*) $$\mathrm{p}=\frac{46550(0\cdot375)^{2\cdot19}}{36\times\sqrt{3\cdot5}}=80\cdot69 \text{ lb. per sq. in.}$$

„ (*c*) $$\mathrm{p}=\frac{90000(0\cdot375)^{2}}{4\cdot5\times36}=78\cdot1 \text{ lb. per sq. in.}$$

„ (*d*) $$\mathrm{p}=\frac{9000(0\cdot375)}{36}=93\cdot74 \text{ lb. per sq. in.}$$

Corrugated Furnace Tubes. The furnace tubes of many boilers are made in one piece, and corrugated. The corrugations, which are placed in a circumferential direction round the tubes, make the tubes much stronger to resist collapse; they also give considerable elasticity in a longitudinal direction and greater heating surface.

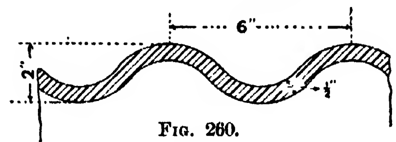


FIG. 260.

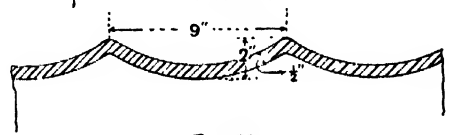


FIG. 261.

In **Fox's** corrugated furnace, with tubes above 2 ft. diameter, the corrugations have a depth of 2 in. and a pitch of 6 in. (Fig. 260). The Board of Trade rule is $\mathrm{p}=14000\mathrm{t}/\mathrm{D}$. Where p and t have the same meaning as before, D = outside diameter at bottom of corrugation in inches.

Morison's Suspension Furnaces. In this form (Fig. 261) the corrugations consist of a series of ribs, or comparatively sharp ridges, pitch 9 in., depth 2 in., connected by *catenary* curves. The Board of Trade Rule is $\mathrm{p}=13500\mathrm{t}/\mathrm{D}$. p and t have the same meaning as before. D is the least outside diameter in inches.

Ex. 2. If the thickness of a corrugated tube is $\frac{3}{8}$ in., diameter 3 ft., find the safe working pressure (*a*) Fox's corrugated Furnace Tube (*b*) Morison's Suspension Tube.

(*a*) $\mathrm{p}=\dfrac{14000\times0\cdot375}{36}=145\cdot8$ lb. per sq. in. (*b*) $\mathrm{p}=\dfrac{13500\times0\cdot375}{36}=140\cdot6$ lb. per sq. in.

Connection of Parallel Plates. The lower parts of the fire boxes of locomotives, vertical, and other boilers, are connected in various ways to the external shell of the boiler. Four such methods are shown in Fig. 262 (I), (II), (III), (IV).

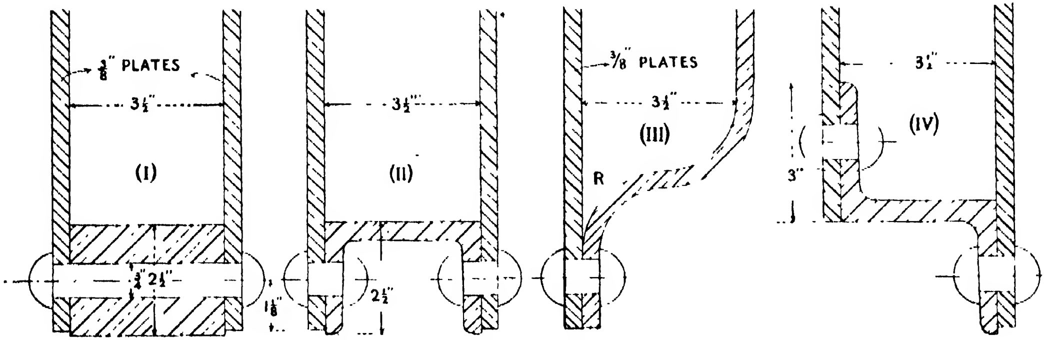


Fig. 262.—Connection of Parallel Plates.

The simplest connection, (I), which is also used for the openings around furnace doors, consists of a riveted solid rectangular bar. It is easily riveted and caulked, and is more generally used than any other for locomotive boilers.

The objections to (III) is that sediment may collect in the recess **R** and cause corrosion of the plates. The form shown in (IV) is rarely used if the pressure exceeds 80 lb. per sq. in.

Intersection of two cylinders. The intersection (or interpenetration) of two cylinders, such as the dome of a boiler, a main and a branch pipe, etc., is of frequent occurrence. In Fig. 263 (I) the intersection of a main and branch pipe is shown. Section planes (which may be either horizontal or vertical), cutting both surfaces, furnish points in the required curve. These planes are most easily obtained by using two semicircles, dividing each into the same number of equal parts and numbering as indicated. The intersection of lines drawn through corresponding points determine points in the required curve. Thus, projectors from the points 0, 1, 2, 3, on the horizontal cylinder to intersect the lines through 0′, 1′, 2′, 3′ determine the points required. Finally, a fair curve is drawn through the points. When, as at (II), the two diameters are equal, the curve of intersection found as in the preceding case consists of two straight lines at 45° to the axis of the pipe. If the branch pipe were made of sheet metal, it would be necessary before bending to the circular shape to cut the metal to the required form. This is effected by obtaining the development.

Draw a straight line **EG** equal to the circumference of the smaller pipe (p. 83) and divide **EG** into twelve equal parts, as at Fig. 263 (III); number these as shown, and draw lines perpendicular to **EG**. Make **E3 33**, and

G3 equal to C3′. Points in the required curve are found by making the distances 2, 2, 1, 1, 0, 0, equal to the perpendicular distances of 2′, 1′ and 0′ from the line AB. Drawing a fair curve through the points, the figure so obtained is the development required, and is the shape to which the sheet metal must be cut before bending.

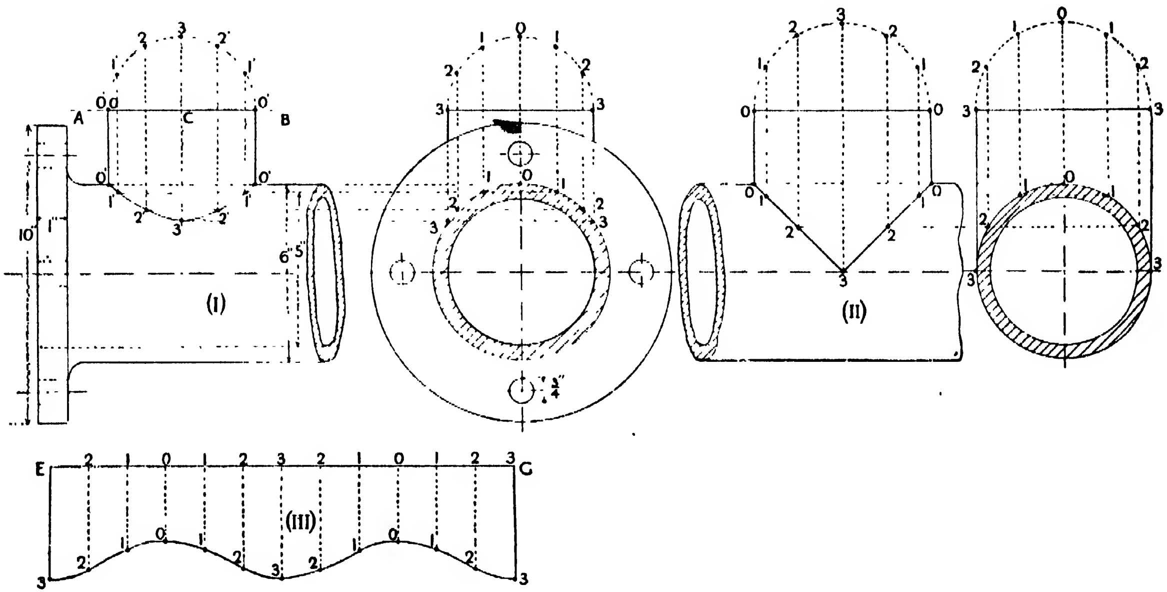


FIG. 263.—Intersection of Main and Branch Pipes.

If the larger cylinder be made by bending a sheet of stiff paper to the cylindrical form, then setting out the development on a similar sheet of paper and bending to a cylindrical form, so that the lines E3, G3 coincide, it will be found that the shape thus obtained will fit the larger cylinder.

Marine Connecting Rod End. In Fig. 264 the elevation, end view, and plan of a portion of a connecting rod end is given, consisting of a round rod and a rectangular block. The diameter of the rod increases as it approaches the

block and the junction of the rod and block produces a curve as shown at C. To determine points in this curve a series of vertical sections indicated by the numbers 1, 2, 3 may be taken, from which points in the curve can be found. Thus, the end view of a vertical section ef will consist of two circular arcs sp, qx and the straight lines pq, xs. The points pq are obviously points on the surface of the block, and a projection line from p intersecting the line ef at 2 is a point in the required curve. To obtain the vertex of the curve, a section mn is taken so that m3 is equal to the

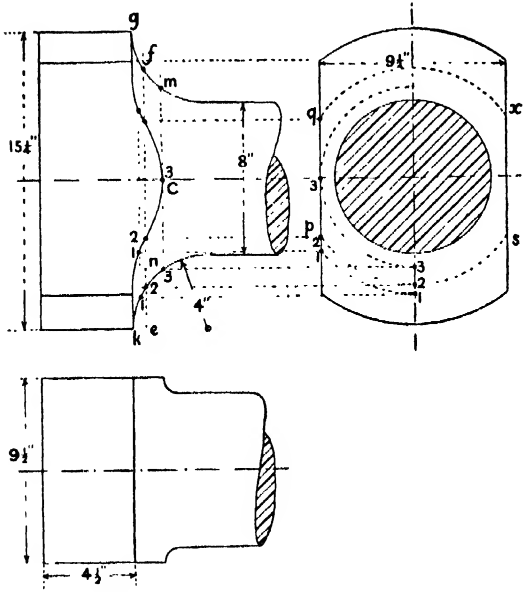


Fig. 264.—Marine Connecting Rod End.

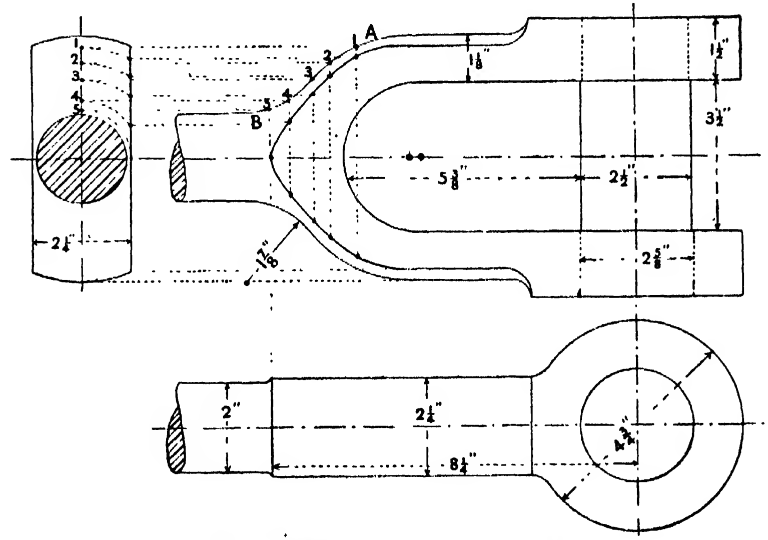


Fig. 265.—Forked End of a Connecting Rod.

width of the block. The limiting points in the curve are obtained by means of a section through gk (the greatest diameter of the rod). Other points can be found by taking sections indicated in Fig. 264, and the curve required can be drawn through the points so obtained. The vertex of the curve will be found to be a point if the width of the block is equal to the least diameter of the rod.

Forked End of a Connecting Rod. Another example of a machine part which is turned and planed (*i.e.* a plane section of a surface of revolution) is shown in Fig. 265 as in the preceding case, a series of vertical sections in the curve AB are taken; then points in the required curve are obtained by projection. Finally, a fair curve is drawn through these points.

Ex. 6. Draw the three views of a connecting rod end to the given dimensions (Fig. 264); also find the curve at C when the width of the block is equal to the rod or 8 in. Scale 6″=1 ft.

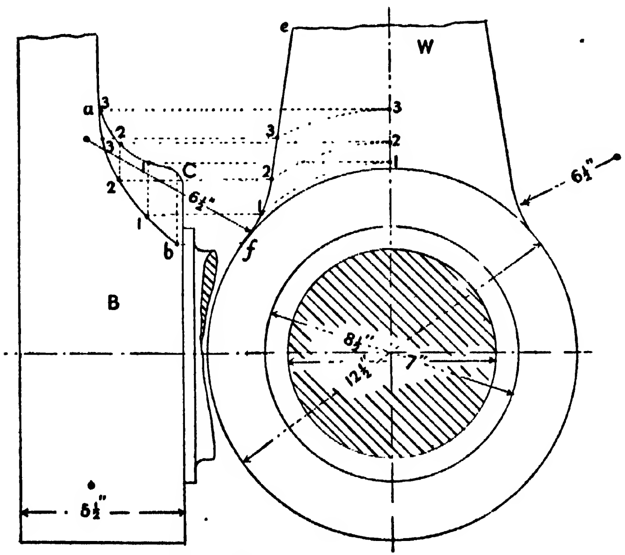


Fig. 266.—Wrought-iron Crank.

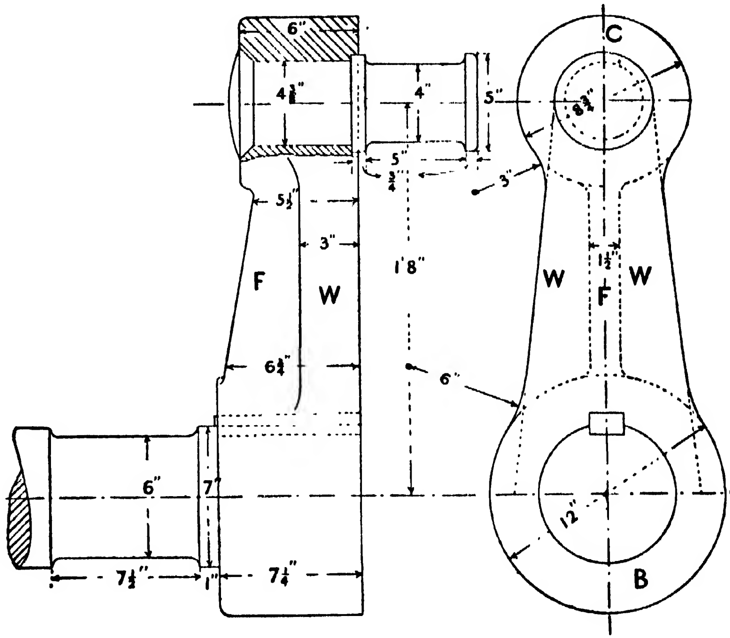


Fig. 267.—Cast-iron Crank.

Wrought-iron Crank. In the elevations of a crank, as in Figs. 216, 217, p. 187, a curve is formed at the junction of the rectangular web and the cylindrical boss. The form and extent of this curve may be obtained by taking a

number of sections (as in the preceding cases), and determining points in the curve. In Fig. 266 the elevation and end view of the larger end of a wrought iron or mild steel crank is shown. The curve of intersection begins at a and ends at b. The latter is obtained by a projective from f where the curve ef touches the boss of the crank.

The remaining points in the curve are found by means of sections, the construction lines of these are shown in Fig. 266.

Cast-iron Crank. The form of this crank is similar to that of the wrought iron crank except that the rectangular web is stiffened by means of one or two feathers F. When one feather is used it is placed in the centre, as in Fig. 267; when two are used they are placed on the edges of the web instead of at the centre.

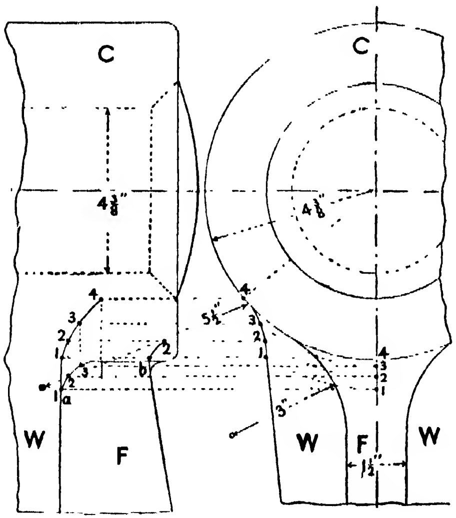


FIG. 268.

The crank is fixed to the crank shaft, and the crank pin to the crank, either by forcing or shrinking (see pp. 187, 188). The curve a, b, at the junction of the web and the boss at the larger end, may be obtained as in the preceding example, and is shown in Fig. 266. At the crank pin end the junction of the web, W, and the boss, C, determines the curve a, 4. Fig. 268. The junction of the boss and the feather F gives the curve b, 2. The construction in both cases is shown in Fig. 268.

Wheel Teeth. The condition for smooth running when two wheels are in gear is that the ratio of their speeds must be constant, or the same as two non-slipping rollers, or cylinders, the diameters of which are the pitch circles of the wheels; hence, from the relation $V=\omega r$ and $v=\omega_1 R$ (p. 95), the velocity ratio V/v must be constant and equal to $\omega r/\omega_1 R$.

In Fig. 269 the points C and D are the centres of a pinion and a wheel; r and R the radii of the pitch circles touching each other at the point P. Two teeth are in contact at m, n where m a point of the tooth on the wheel is in contact with n a point on the tooth of the pinion.

From geometry it is known that when two curves (omitted in Fig. 269) are in contact they have a common perpendicular TT.

The points, m on the tooth of one wheel, in contact with the point n on the other, are moving with different velocities, the point m moving in the direction of the tangent to the circle, centre D, velocity v, the point n in

the direction of the tangent to the circle centre **C**, velocity **V**; but the components of these velocities along **TT** must be the same or the two points **m** and **n** would have relative motion along the line **TT**. Let V_1 denote the component velocity of **m** and **n** in the direction of **TT**, draw **DM**, **CN**, from the centres **D** and **C** perpendicular to the line **TT**, then the ratio of the angular velocities is given by

$$\frac{V_1}{DM} \div \frac{V_1}{CN} = \frac{CN}{DM} = \frac{CP}{DP} = \frac{r}{R}.$$

The required condition is, therefore, that the common perpendicular to the profiles of the teeth at any point where they are in contact must pass through the pitch point. This condition is satisfied either by **Cycloidal** or by **Involute** curves, and portions of one of these curves are used for the profiles of the teeth of wheels. (Neglecting friction, the pressure between the teeth is in the direction of the common perpendicular at the point of contact.)

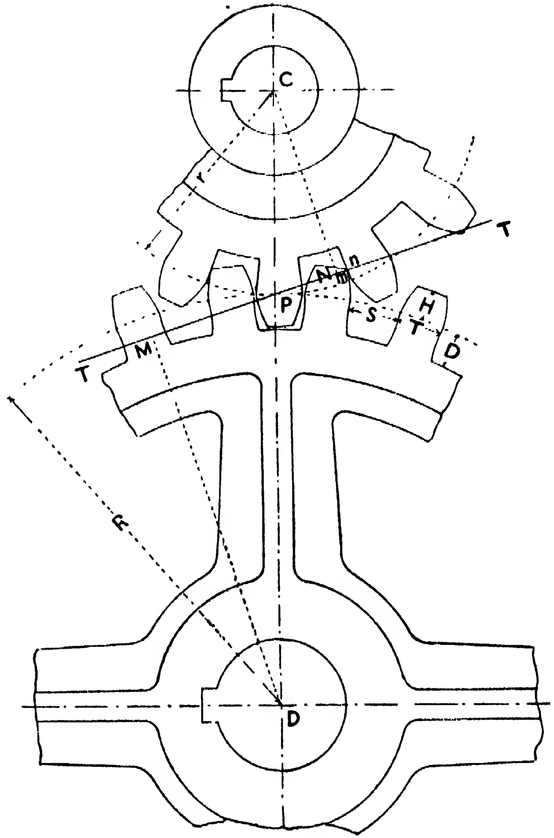


Fig. 269.

Cycloid. One method of describing a cycloid is given on p. 101. Another is as follows:—Draw the rolling circle, the tangent at **A** and make **A** 6″, equal to the arc **A**.6 (p. 83). Divide the arc and the straight line each into the same number of equal parts. Fig. 270. Draw lines parallel to **AB** through 1, 2 ... 6. As the circle rolls along **AB** the points 1, 2 ... 6 coincide in turn with the points 1″, 2″ ... 6″. Using each point 1′, 2′ ... 6′ on the path of the centre in turn, radius equal to that of the rolling circle, points on the required curve are obtained.

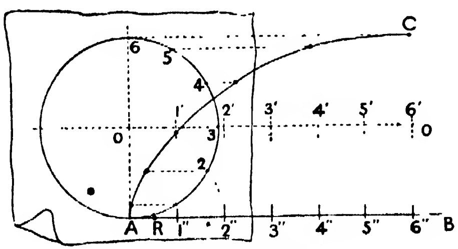


Fig. 270.—Cycloid.

Rack and Pinion. A cycloidal curve may be used for the teeth of a rack, Fig. 271; thus, assuming the rack to be fixed, a point on the teeth of a wheel in contact with it will during its motion describe a cycloid, and hence the wheel will leave the rack smoothly if the face of each tooth of a rack is made of a cycloidal form. The flanks of the teeth are usually made radial.

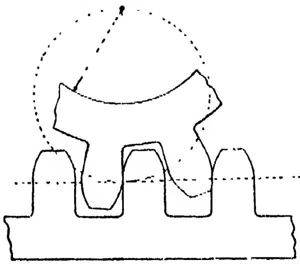


FIG. 271.—Rack and Pinion.

Epicycloid and Hypocycloid. The curve traced out by a point on the circumference of a circle rolling on the outside of another (fixed circle) is an *epicycloid*, when it rolls on the inside a *hypocycloid*. Let **C**, Fig. 272, be the centre of the fixed circle of which a portion **AB** is shown. **D** and **E** are the centres of the rolling circles in contact with the fixed circle at **P**. The constructions necessary to obtain points in both curves are the same as these used in drawing a cyloid. Fig. 270.

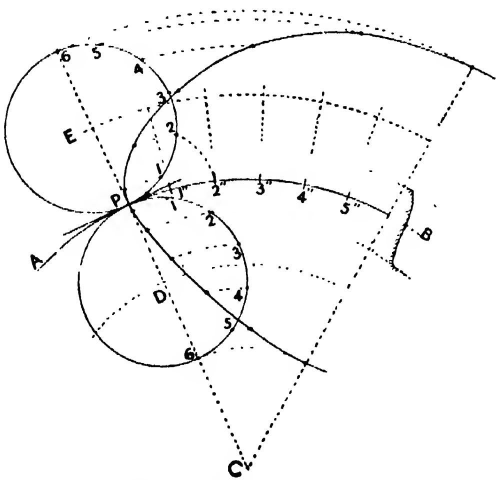


FIG. 272.—Epicycloid and Hypocycloid.

Involute of a Circle. *If a straight line roll on a curve, the locus of any point on the line is called an involute of the curve.* To draw an involute of the circle **OABD**, Fig. 273, make **OC** equal to the semi-circumference **OAB** (p. 83). Divide each into the same number of equal parts and draw tangents to the circle at points 1, 2 ... 6. Make the distances 11″, 22″ ... 66″ equal to 01′, 02′ ... 06′, a fair curve through the points 0, 1″ ... 6″ is the involute required.

Involute Teeth. Involute teeth for wheels are usually better adapted for general purposes than those of cycloidal form. The *path of contact* (locus of the points of contact of a pair of teeth) is a straight line inclined at 75° to the line of centres, or 15° to the tangent at the pitch point. With involute teeth the direction of the pressure

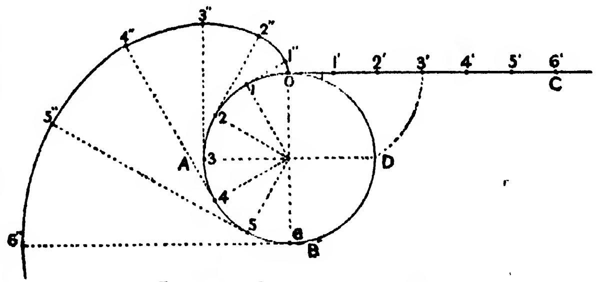


FIG. 273.—Involute of a Circle.

between the teeth is constant, instead of being variable as in cycloidal teeth. All involute teeth of the same pitch will gear together; also the distance between the axes of the wheels may be slightly altered without any change in the smooth working of the wheels.

The curves for the teeth may be obtained by drawing an involute as in Fig. 273 or by drawing a straight line on a piece of tracing paper, placing the line in contact with the curve, and by means of a needle point rotating the line about the base circle. Mark the ends of the line, and finally obtain a circular arc to pass through the points; in this manner the required curve can be obtained. An approximate method given by Prof. Unwin may be stated thus:—

Draw (Fig. 274), the pitch circle **AB**, the tangent **TT** at **P**, and the line **CP** at 15° to **TT**; the base circles are drawn touching the line **CP**. Make **Pn** equal to the height of a tooth, and $mg = \frac{3}{8}mn$; draw the line **fg** touching the base circle at **f**; then **c** the required centre is found by making $fc = \frac{1}{4}fg$, and a circular arc radius **cP** determines the required curve **PO**.

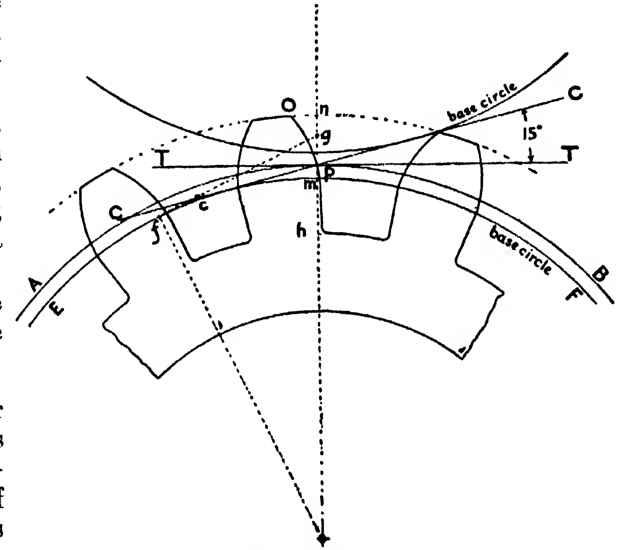


FIG. 274.—Involute Teeth.

The flanks of the teeth within the base circle are made radial. Contact of the teeth does not take place within the base circle.

Helical and Screw Gearing. When two wheels are in gear the motion becomes smoother as the pitch of the teeth is reduced, but this reduces the strength by diminishing the thickness of the teeth. The difficulty is obviated as follows:—if the teeth of a spur wheel instead of being parallel to the axis of the wheel are twisted through a definite angle, then what is called a single helical wheel is obtained. Fig. 275 (I). Two such wheels will gear together when the angles of the teeth are the same and they are suitably geared, but the obliquity produces side pressure. This difficulty is overcome by using double helical wheels shown at (II); the angle is usually about 30°. Helical wheels with machine-cut teeth transmit motion uniformly and noiselessly both for high and low speeds; they are largely used for milling machines, cranes, etc., also in reducing gears from a steam turbine to propeller shaft. Thus, in a Parsons double reduction geared turbine, 3510 rev. per min., driving a

propeller shaft at 78 rev. per min., the reduction gearing of 1 : 45 in two steps is effected by using wheels and pinions of double helical type ; the wheels are of cast iron with steel tyres shrunk on, the pinions of nickel steel, axial pitch $\frac{7}{12}$ in. and 1 in. respectively, angle of teeth 30°.

Worm Gearing. A worm wheel **W** consists of a wheel with the teeth set obliquely on its rim, and gearing with the thread of a screw **SS**. Fig. 276. The wheel will advance one, two or three teeth for each revolution of the worm **SS** according as the screw thread consists of a single, double or triple thread.

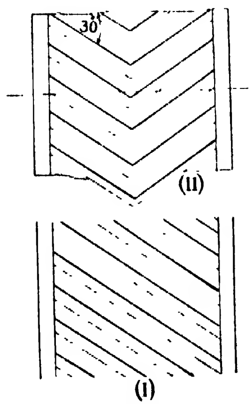


FIG. 275.—Helical Wheels.

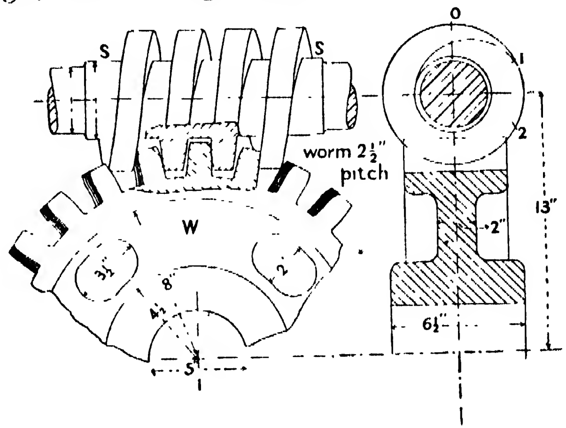


FIG. 276.—Worm and Worm Wheel.

Worm gearing may be used for reducing speed, as in some electric motors, for tightening the packing in a gland, Fig. 186, etc.

The worm and wheel are usually made so that the worm drives the wheel ; in light mechanism the wheel may be used to drive the worm by increasing sufficiently the obliquity of the teeth. The section of the teeth of the worm and wheel are the same as those of a rack and pinion in gear.

Built-up Wheels and Pulleys. The rim and arms of a pulley may be made of wrought iron or mild steel, and the nave of cast iron as in Fig. 112 (p. 84). Pulleys of this kind are lighter than those of cast iron and more trustworthy at high speed. For convenience in handling and manufacture, spur and fly-wheels of large diameter are

usually *built-up*. One method of fastening the segments of the rim to each other and to the arms is illustrated in Fig. 134 ; another method is shown in Fig. 277. The arms and nave of the wheel may be cast in one piece as in Fig. 278. To lessen the strains due to unequal contraction in cooling the nave is frequently slotted between the

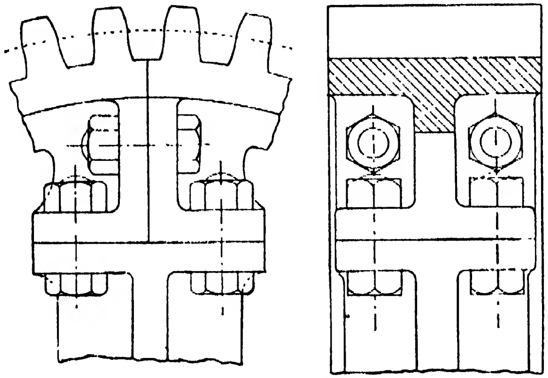


Fig. 277.—Rim of built-up Wheel.

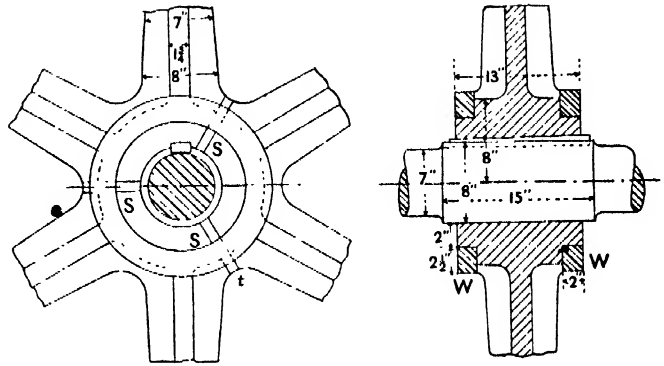


Fig. 278.—Boss and Arms of Spur Wheel.

arms, as at **SS** These are fitted with metal plates, and finally wrought iron or steel rings, **WW**, are shrunk on to hold the parts of the nave firmly together.

TYPICAL EXAMINATION QUESTIONS.

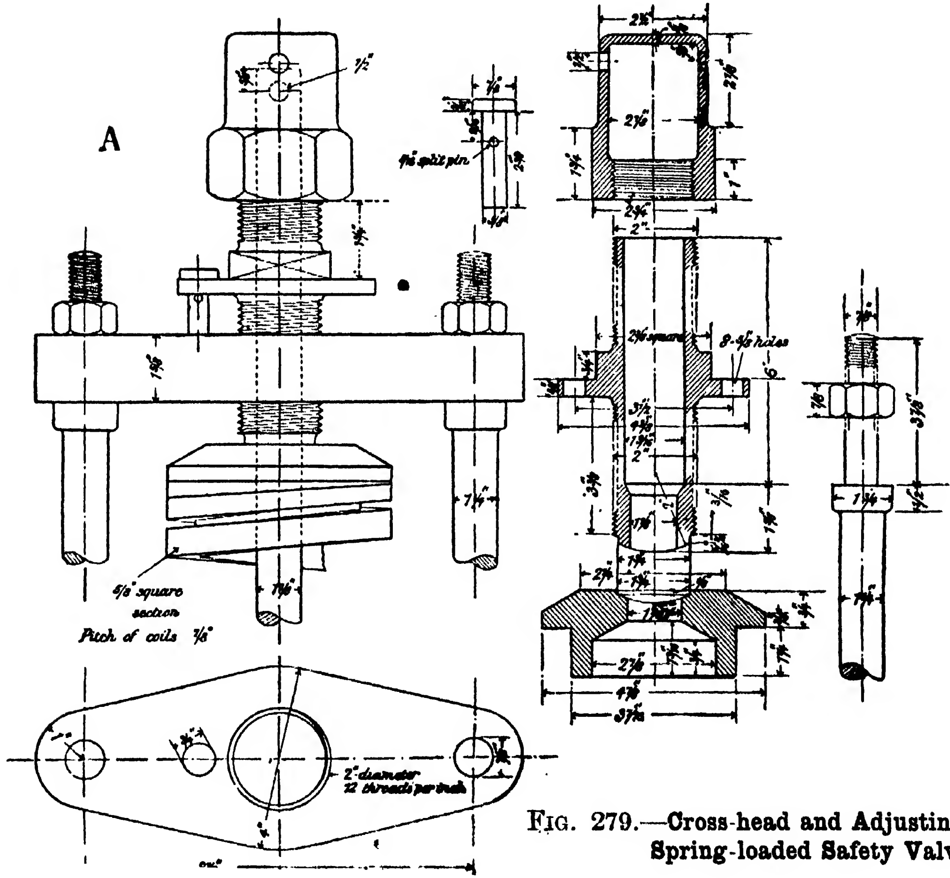


FIG. 279.—Cross-head and Adjusting Screw of a Spring-loaded Safety Valve.

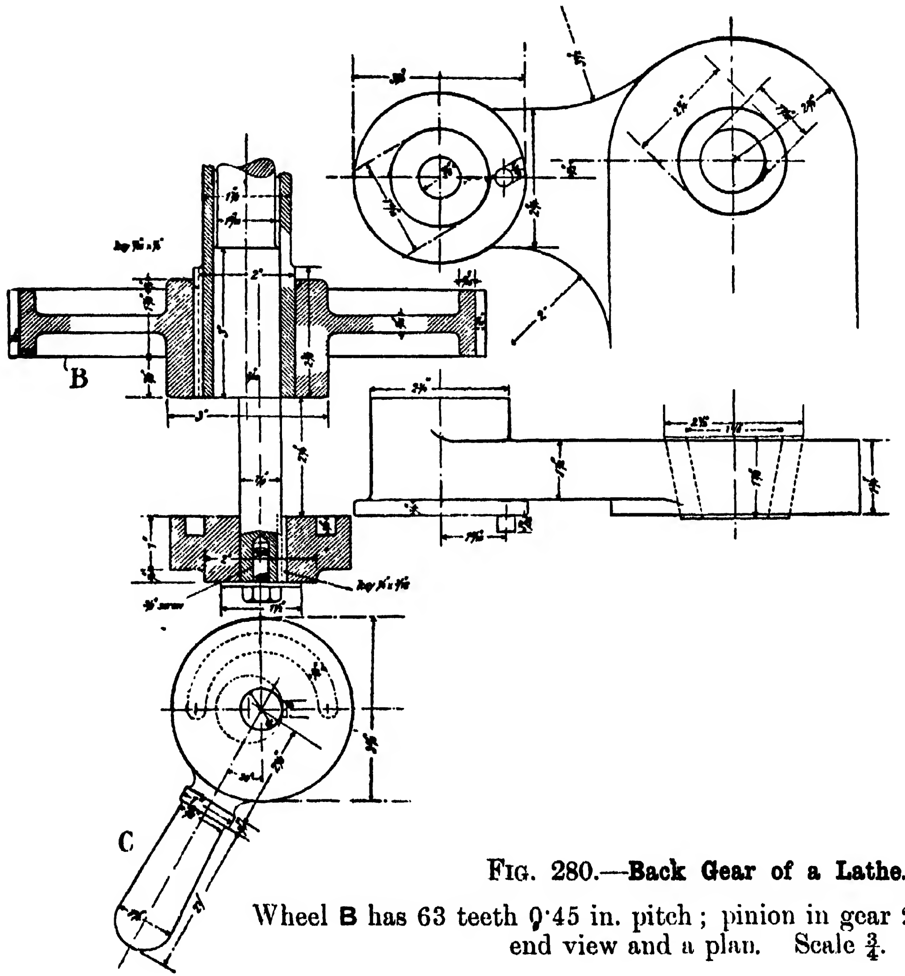


FIG. 280.—**Back Gear of a Lathe.**

Wheel B has 63 teeth 0·45 in. pitch; pinion in gear 21 teeth. Draw an end view and a plan. Scale $\frac{3}{4}$.

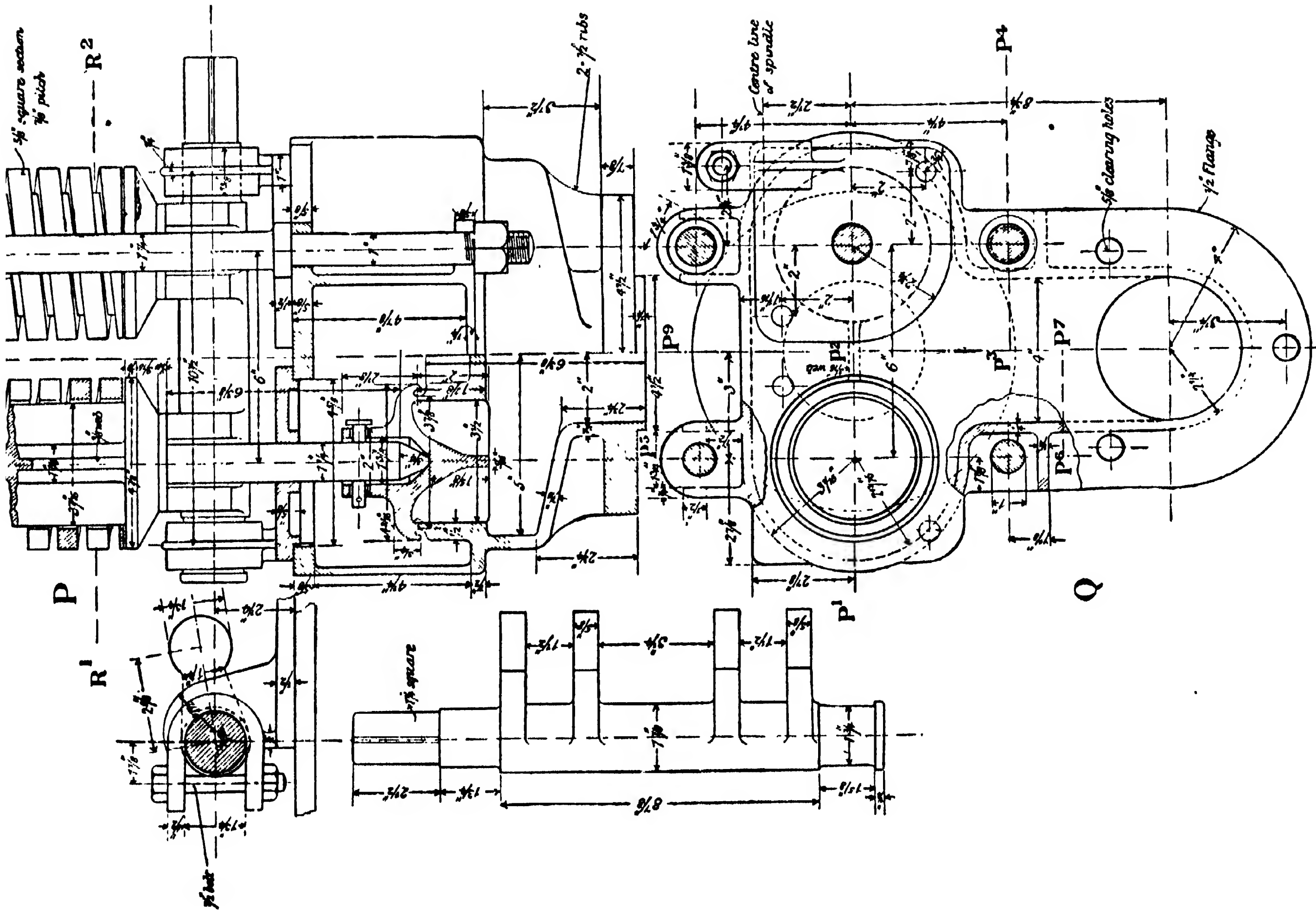


FIG. 281.—**Double Spring-loaded Safety Valve for Boilers.**

View **P** is a sectional elevation taken along the line $P^1P^2P^3P^4$ of figure **Q**, and view **Q** is a plan with parts removed. Draw views shown,

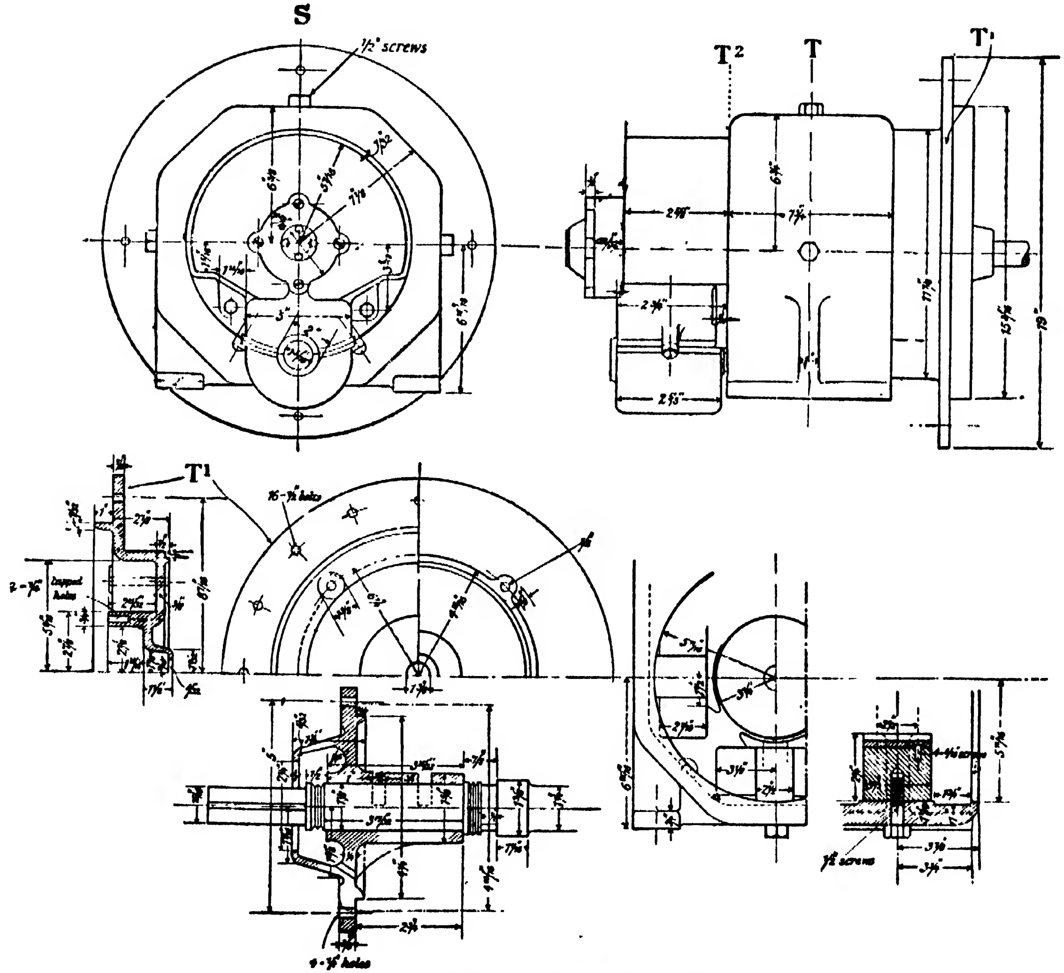


FIG. 282.—Four-Pole Electric Motor.

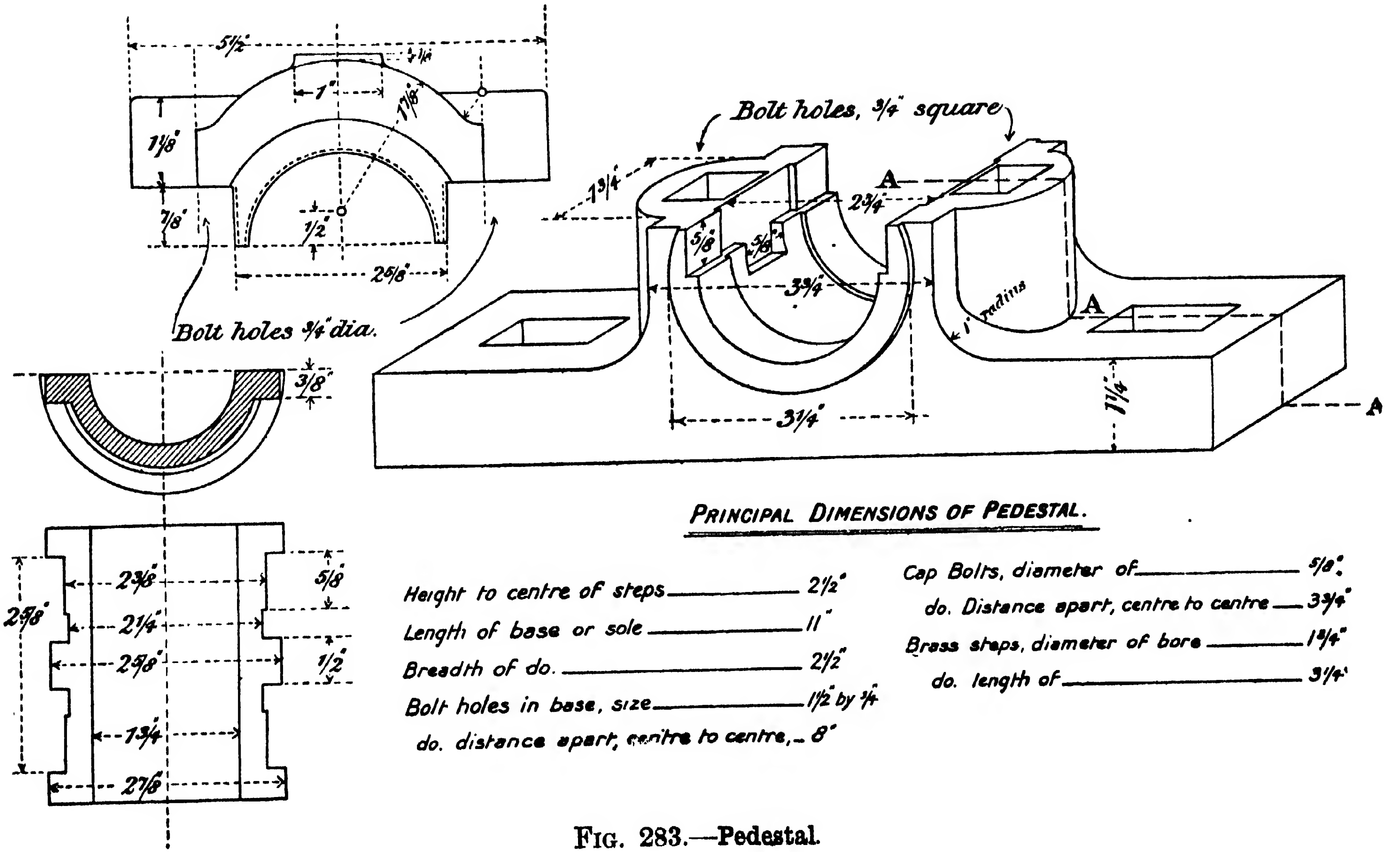


FIG. 283.—**Pedestal.**

Draw elevation, end view and plan, scale, full size.

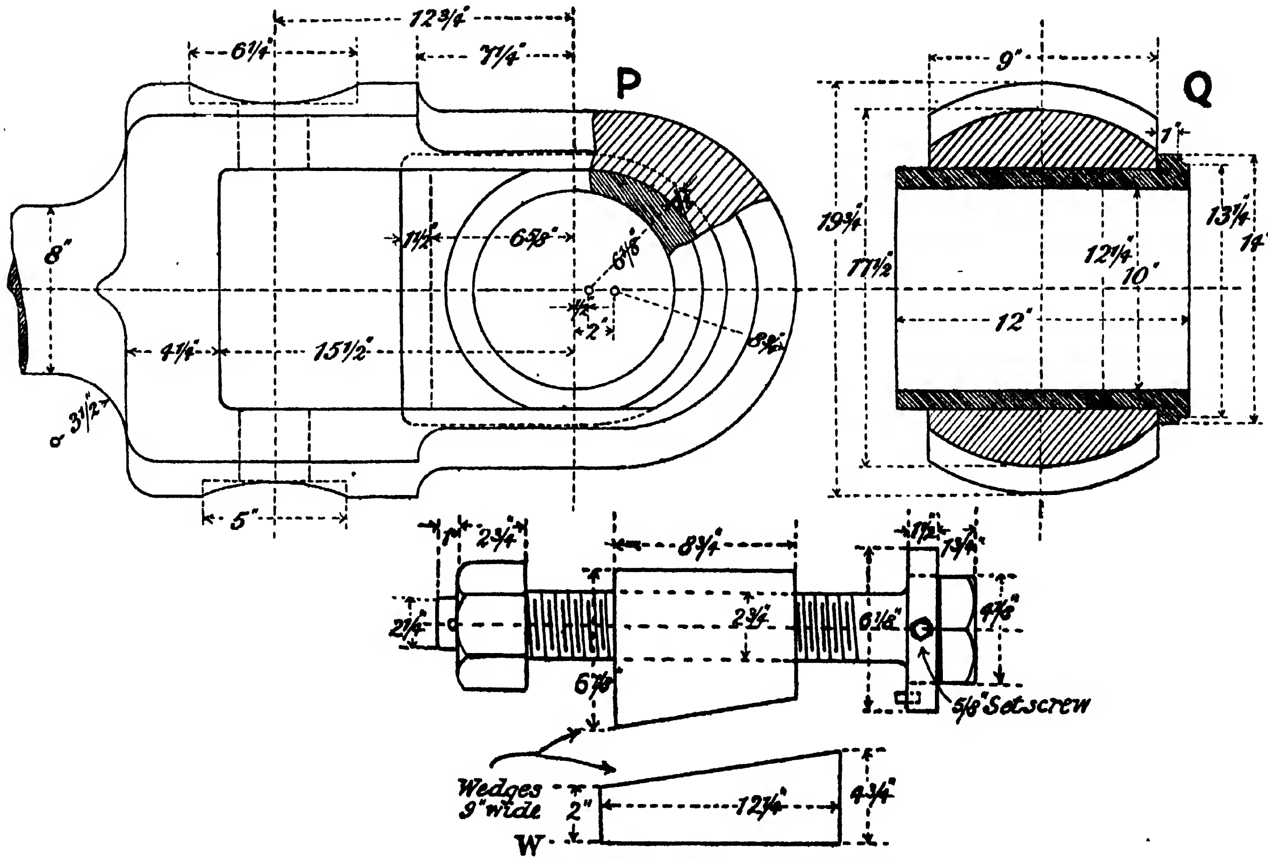


FIG. 284.—**End of Connecting-rod.**

Draw elevation, end view and plan. Scale ¼.

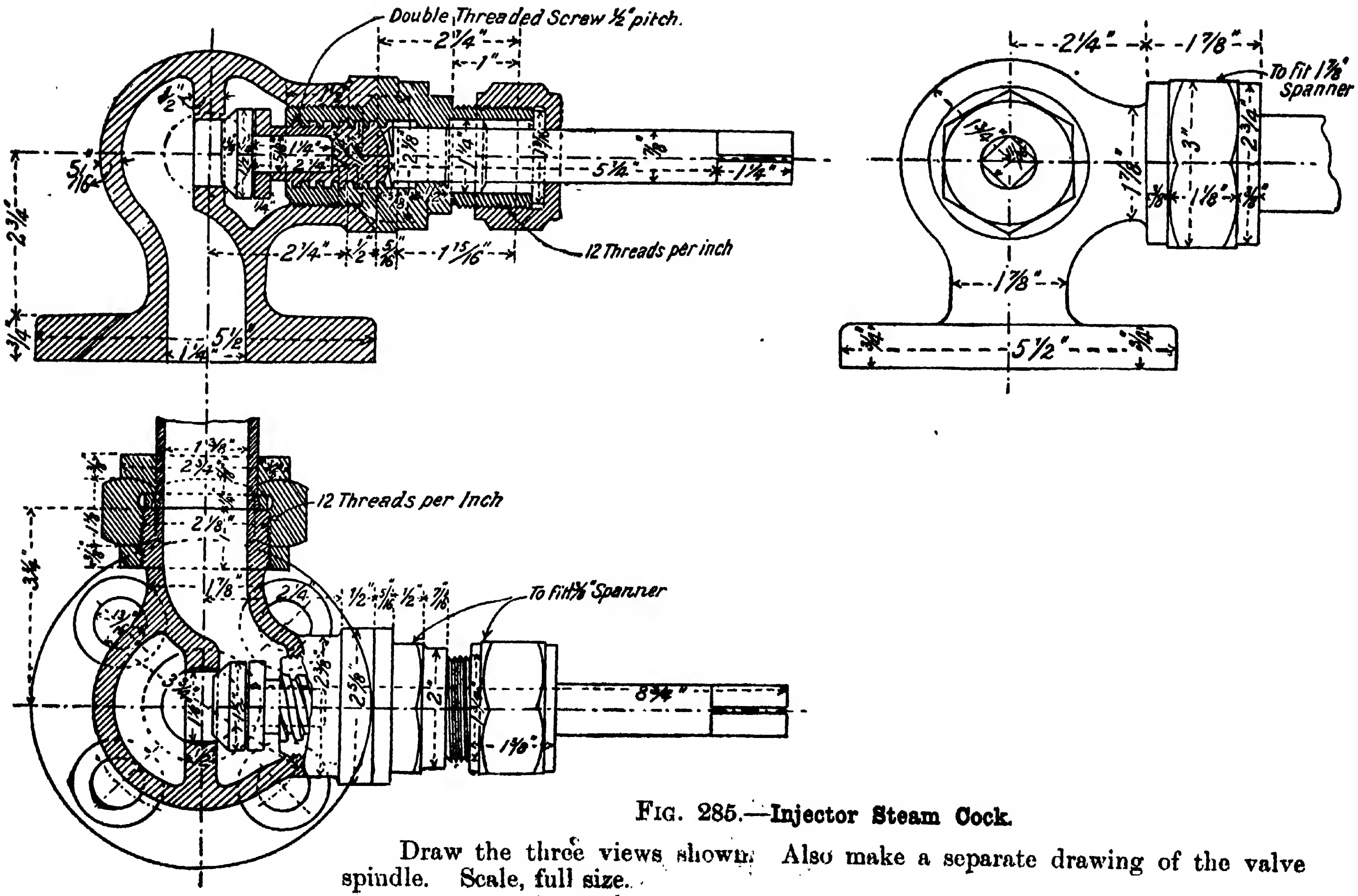


FIG. 285.—**Injector Steam Cock.**

Draw the three views shown. Also make a separate drawing of the valve spindle. Scale, full size.

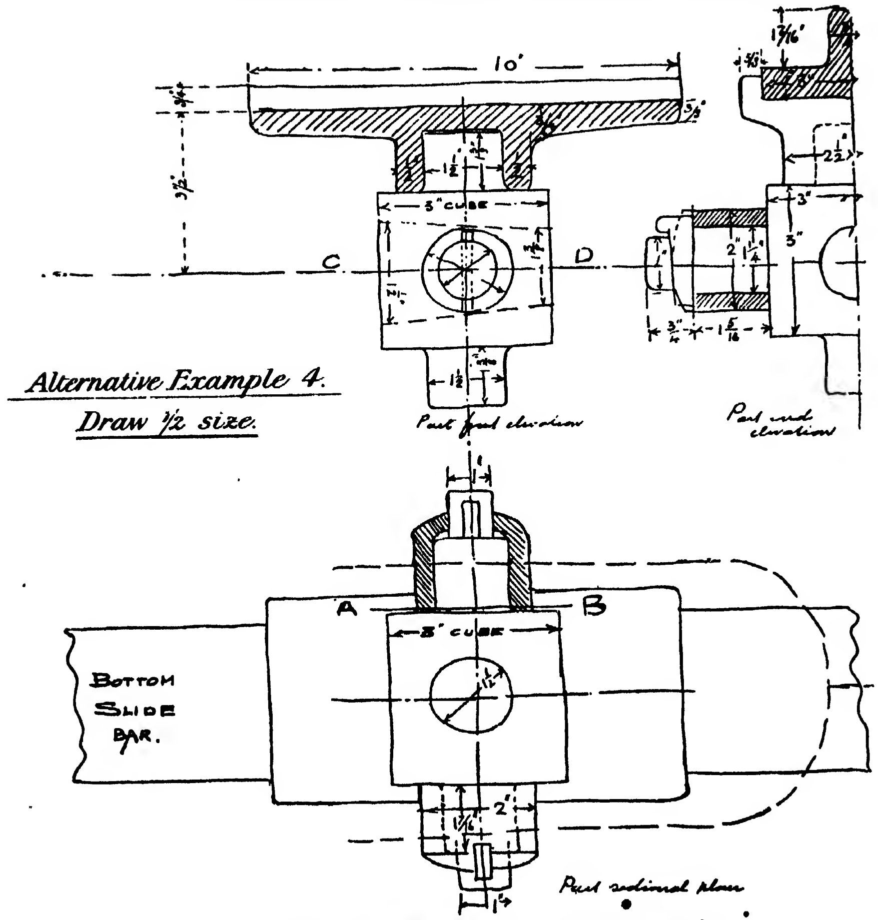


FIG. 286.—**Crosshead for a Steam Engine.**

Sketches from a draughtsman's note-book. Complete the three views shown. Scale ½.

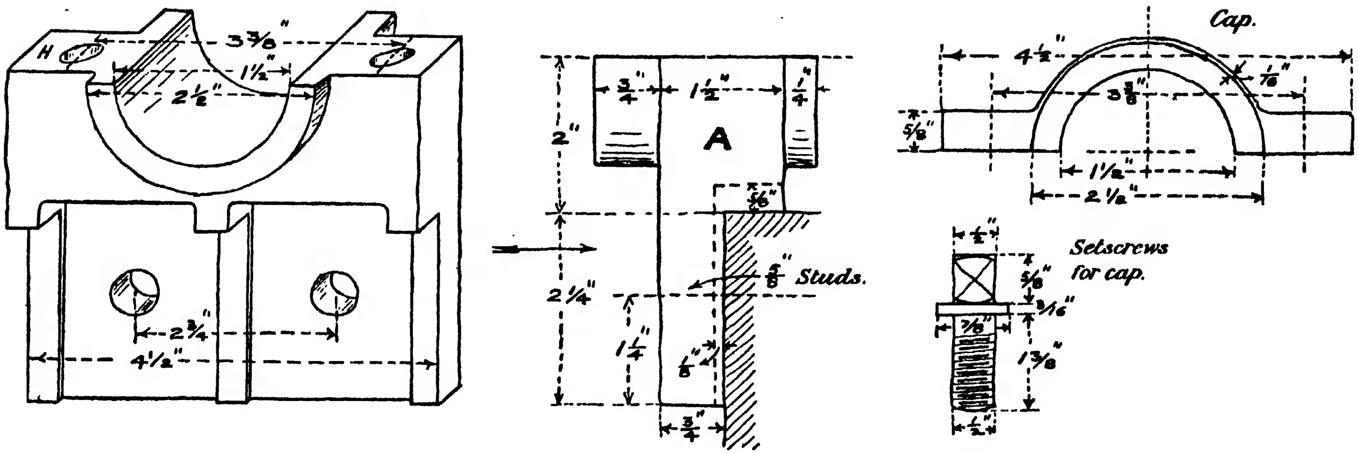


FIG. 287.—$1\frac{1}{2}$-inch bearing.

The diagram gives dimensioned hand-sketches of details of a simple bearing. Draw full size, inserting dimensions:

(*a*) An elevation corresponding with **A**, but in section, adding the cap and one of the ⅝″ studs.

(*b*) An elevation, projected from (*a*), looking on the face indicated by the arrow. In this view the cap, cap screws, and the ⅝″ studs should be shown.

(*c*) A plan.

N.B.—Do not draw the pictorial view, nor the parts separated as in the diagram. Dotted lines, representing hidden parts, are not required.

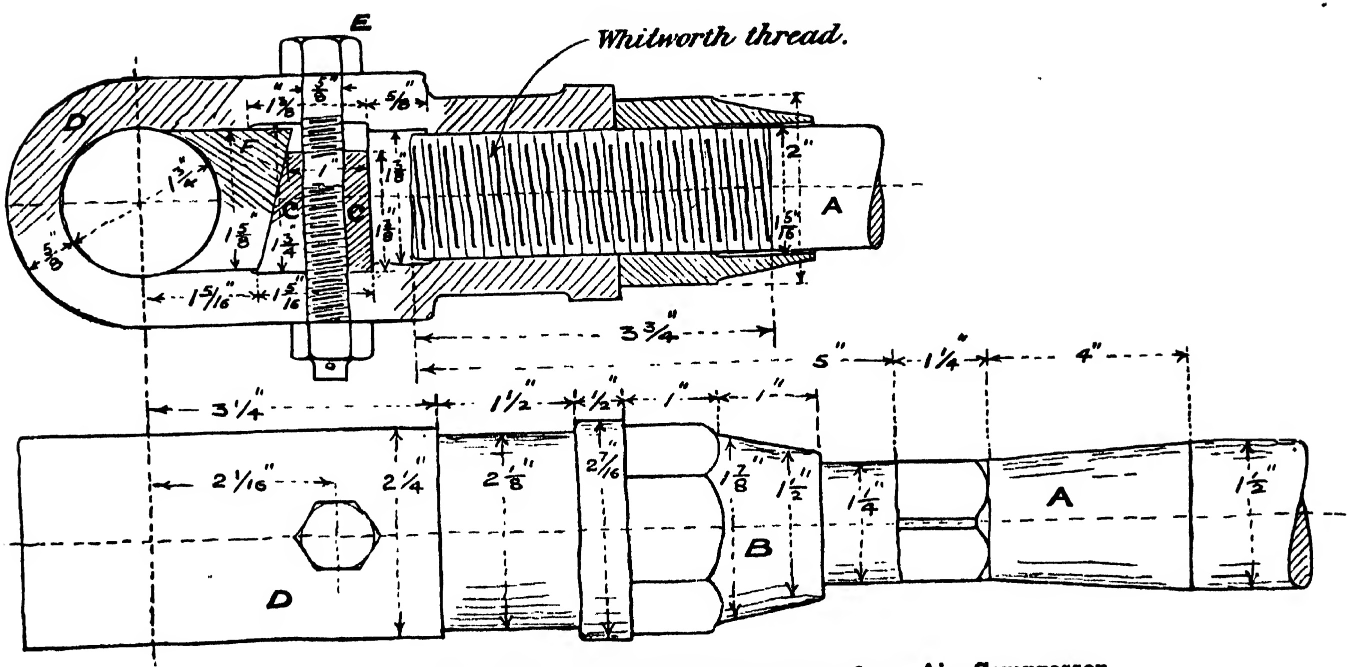


Fig. 288.—**End of a Connecting-Link of an Air Compressor.**

Make full size separate scale drawings of details, with dimensions, as follows :

(*a*) A longitudinal and an end view of the rod end **A**. The screw thread may be drawn in the manner shown.

(*b*) Three views of the nut **B**.

(*c*) Three views of the wedge **C**.

(*d*) Three views of the head **D**.

N.B.—No credit will be given for drawing the parts assembled, as in the diagram. Dotted lines, representing hidden parts, are not required.

Questions.

The Sketches in answer to these questions should be drawn freehand.

1. Sketch full size, inserting dimensions, two views of a wheel boss, fixed to a shaft by means of a sunk gib key, as follows:

Diameter of shaft,	2″
Diameter of boss,	4″
Length of boss,	3″
Width of key,	$\frac{5}{8}$″
Depth of key,	$\frac{3}{8}$″
Taper of key, $\frac{1}{8}$″ per foot.	

2. Name the materials of which the parts of the $1\frac{1}{2}$ inch Bearing, Fig. 287, and the several parts **A**, **B**, **C**, **D**, **E** and **F** of the end of connecting link of an Air Compressor, Fig. 288, would be constructed.

3. Sketch full size, inserting dimensions, a 1″ rag bolt *or* Lewis bolt, suitable for securing the frame of a machine to a stone foundation. Explain how the bolt is fixed in the stone.

4. Explain briefly, with sketches, how you would set out, drill, and tap the hole marked **H** in the $1\frac{1}{2}$ inch Bearing on the diagram, Fig. 287.

5. Sketch in section the armature of a small drum wound motor, showing clearly how the stampings are secured.

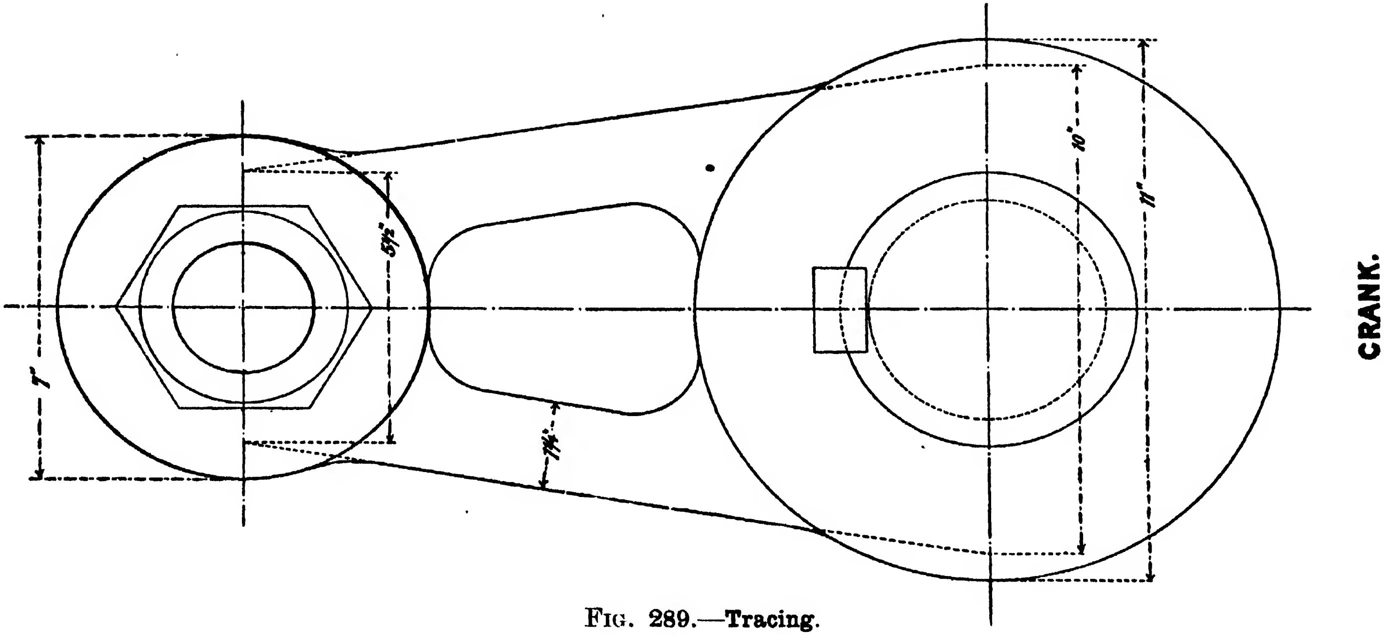


FIG. 289.—**Tracing.**

Trace in ink the drawing of a crank shown.

The lines should be very black, of uniform and moderate width, and as continuous as possible.

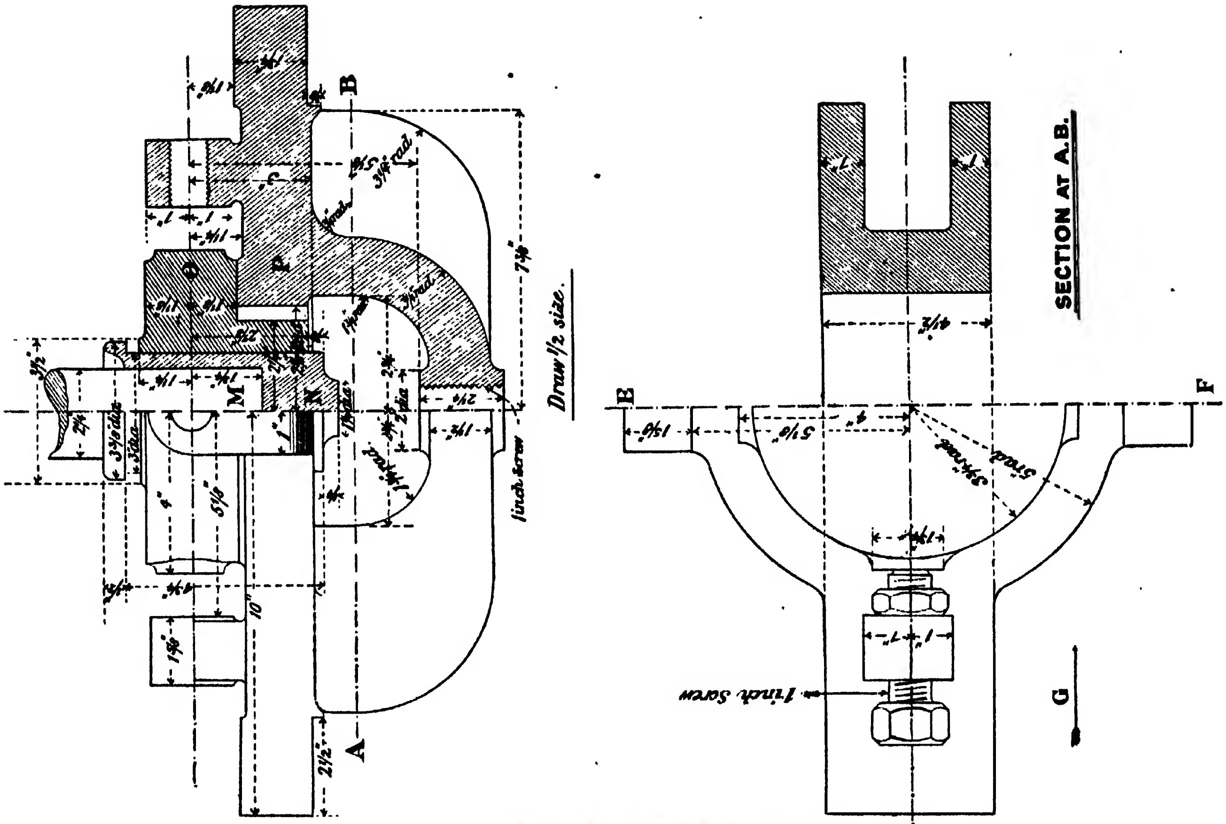


FIG. 290.—**Adjustable Footstep Bearing.**

Draw to scale and complete the two projections partly shown in diagram, and also draw a vertical section through line EF, correctly projected, looking in the direction of the arrow G.

Scale, ½ size. No dotted lines need be shown, and figured dimensions need not be inserted.

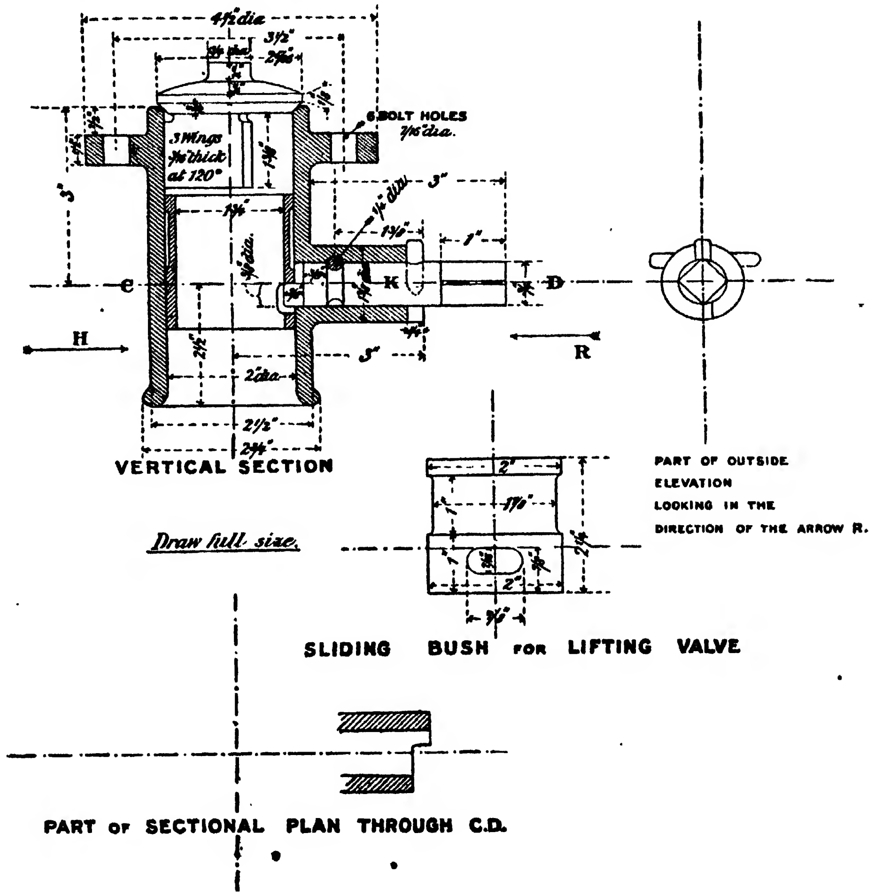
FIG. 291.—**Lift Valve.**

Draw, full size, an outside view corresponding to the vertical section shown. Draw also a sectional plan through line **CD**, with the spindle **K** removed. Finally draw a sectional elevation taken through the centre line, looking in the direction of the arrow marked **H.**

Also make a plan and the two end elevations of the spindle marked **K**, all the necessary dimensions being shown on it.

Scale, full size.

No dotted lines need be shown and figured dimensions need not be inserted in the three first views.

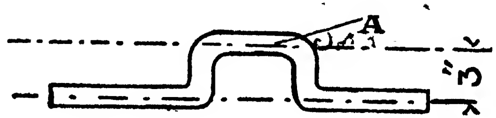


Questions.

The Sketches in answer to these questions should be drawn freehand on squared foolscap paper.

1. State of what materials you would make the parts marked M, N, O, P, in the footstep drawing, Fig. 290. Also sketch an arrangement to prevent the rotation of the footstep bearing (N) in the casting O.

2. A wrought iron crank shaft is formed by bending a 2″ round bar as shown in sketch.



How would you proceed to turn the part marked A?

3. A plate girder is made up of a vertical web 2′ deep connected to top and bottom flanges, 1′ wide, by two angle irons 3″ × 3″ × ½″. The web and flange plates are ½″ thick. Sketch a section of the above girder, putting in the necessary dimensions. Show also a suitable stiffener.

4. Sketch to scale, half size, inserting dimensions, a double-rivetted butt joint with two straps, as used in the longitudinal joint of a boiler. Rivets, ⅞″ diameter, pitch, 3″, and thickness of plate ¾″. What would be the efficiency of this joint?

5. Show, by sketches, the method of holding and insulating the bars of a commutator of a continuous current dynamo. The shaft is 3″ diameter, and the outside of the bars 8″ diameter.

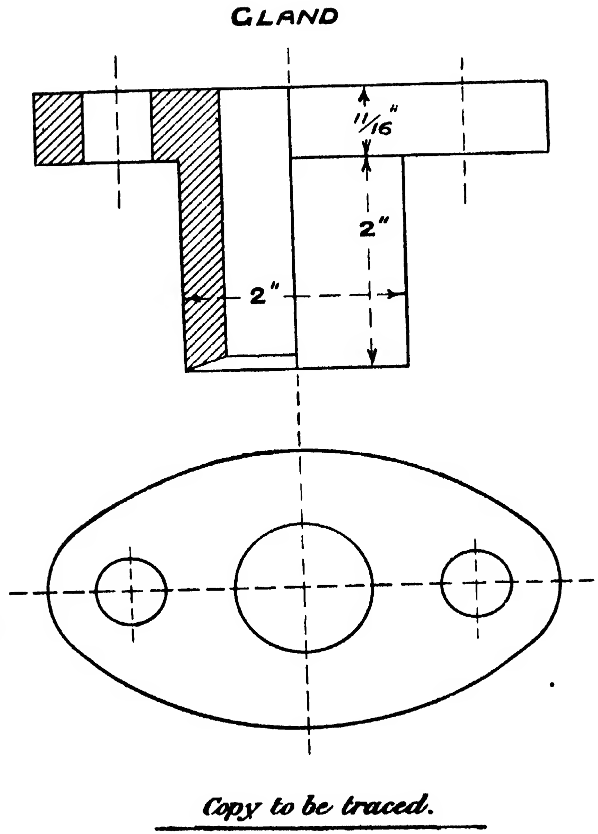


FIG. 292.—**Tracing**.

Trace in ink the two views of the gland shown on Diagram. Insert the dimensions and print the title as shown.

The lines should be very black, of uniform and moderate width, and as continuous as possible.

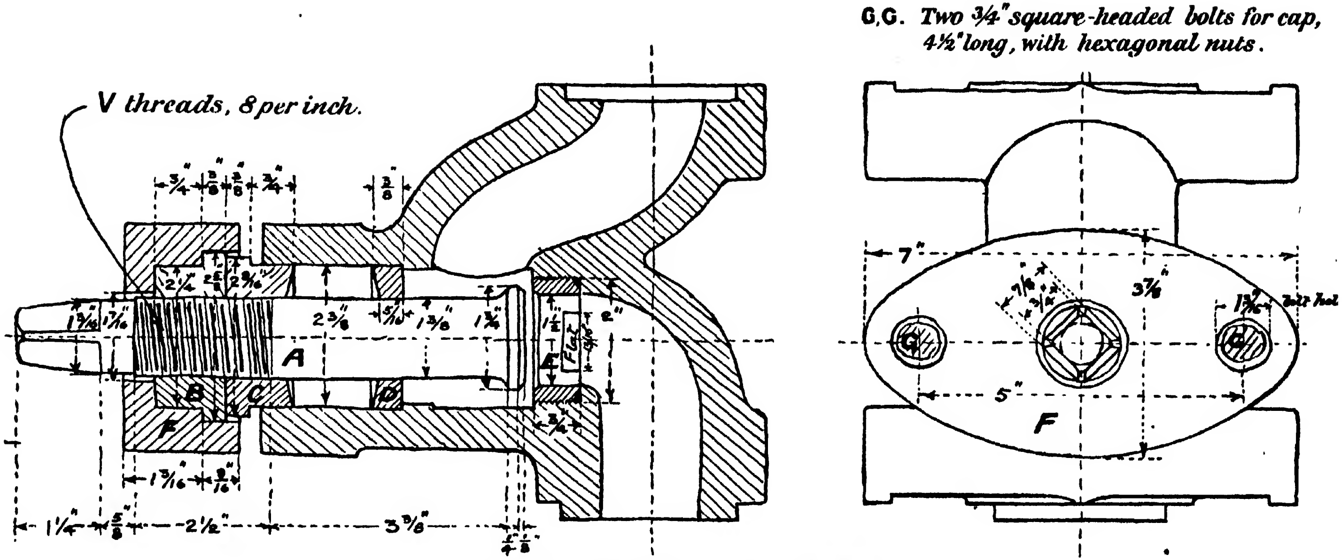


Fig. 293.—**Hydraulic Stop Valve.**

Make full size separate scale drawings of details, fully dimensioned, as follows:—

(*a*) Two views of the valve spindle **A**. The screw thread may be shown conventionally, as in the diagram.

(*b*) Two views of the nut **B**.

(*c*) Two views of the gland **C**.

(*d*) Two views of the bush **D**.

(*e*) Two views of the seating **E**.

(*f*) Three views of the cap **F**.

(*g*) Three views of one of the $\frac{3}{4}''$ cap bolts **G**, with nut.

N.B.—No credit will be given for drawing the parts assembled, as in the diagram. Dotted lines, representing hidden parts, are not required.

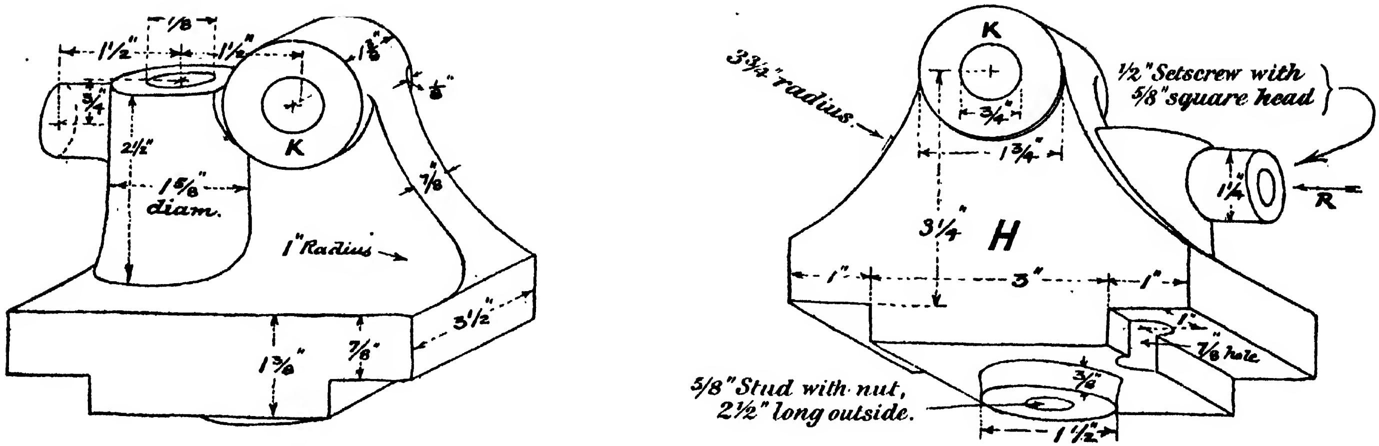


Fig. 294.—**Bracket.**

The form and dimensions of a bracket (for a lathe bed) are exhibited by two pictorial views. Draw full size, inserting dimensions :—

(*a*) An elevation, as seen when looking in the direction of the arrow **R**. Put in the $\frac{1}{2}''$ setscrew and $\frac{5}{8}''$ stud.

(*b*) A sectional elevation on a plane parallel to the face **H**, and 1″ distant therefrom; that is, the section plane is taken through the axis of the $\frac{1}{2}''$ setscrew and $\frac{7}{8}''$ hole.

(*c*) A plan.

N.B.—Do not draw the pictorial views. Dotted lines, representing hidden parts, are not required.

Questions.

The Sketches in answer to these questions should be drawn freehand.

1. Indicate the parts of the stop valve, Fig. 293, which you would make respectively of brass, cast iron and wrought iron. Sketch a method of preventing the nut B from turning in the cap F.

2. Explain briefly, with sketches, how you would drill or bore the $\frac{3}{4}''$ hole K, and true up the faces marked K, K, in the bracket Fig. 294.

3. You are given the dimensions of a shaft coupling of the ordinary muff or box type. Make dimensioned sketches, half size, consisting of an end view and a longitudinal section, with the shaft ends secured by keys.

Diameter of coupling outside - - - - - -	$4\frac{1}{2}''$
Diameter of bore of coupling - - - - - -	$2''$
Length of coupling - - - - - - - -	$7''$
Width of keys - - - - - - - -	$\frac{5}{8}''$

4. Sketch in section, full size, inserting dimensions, a steam engine piston $6''$ diameter and $1\frac{3}{4}''$ wide, with three Ramsbottom rings of section $\frac{1}{4}''$ square. The conical hole for the piston-rod is $1\frac{3}{8}''$ diameter at the larger end, and the taper is $1''$ per foot.

5. Describe briefly, with sketches, any method you would consider suitable for joining together the ends of a stranded cable made up of seven copper wires, each of No. 20 gauge, for carrying an electric current.

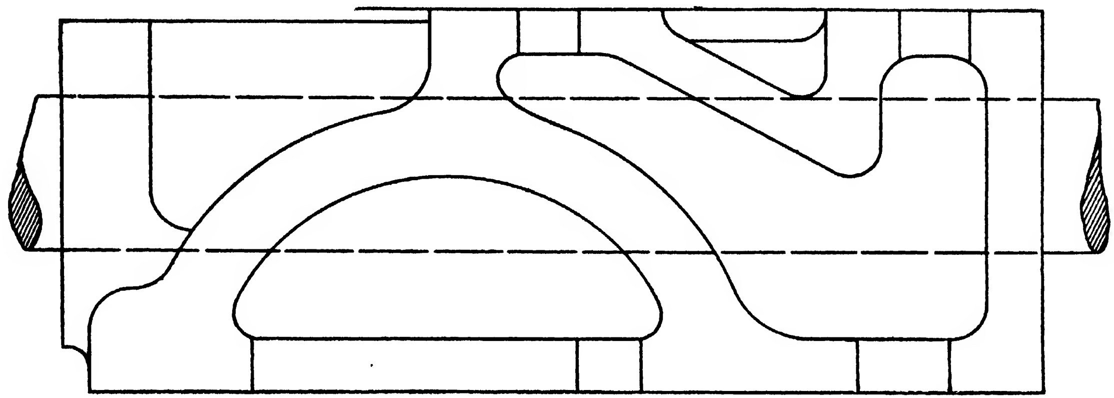


FIG. 295.—**Expansion Valve.**

Tracing.

Trace in ink the expansion valve shown.
The lines of the tracing should be black, uniform in width, and of moderate thickness.

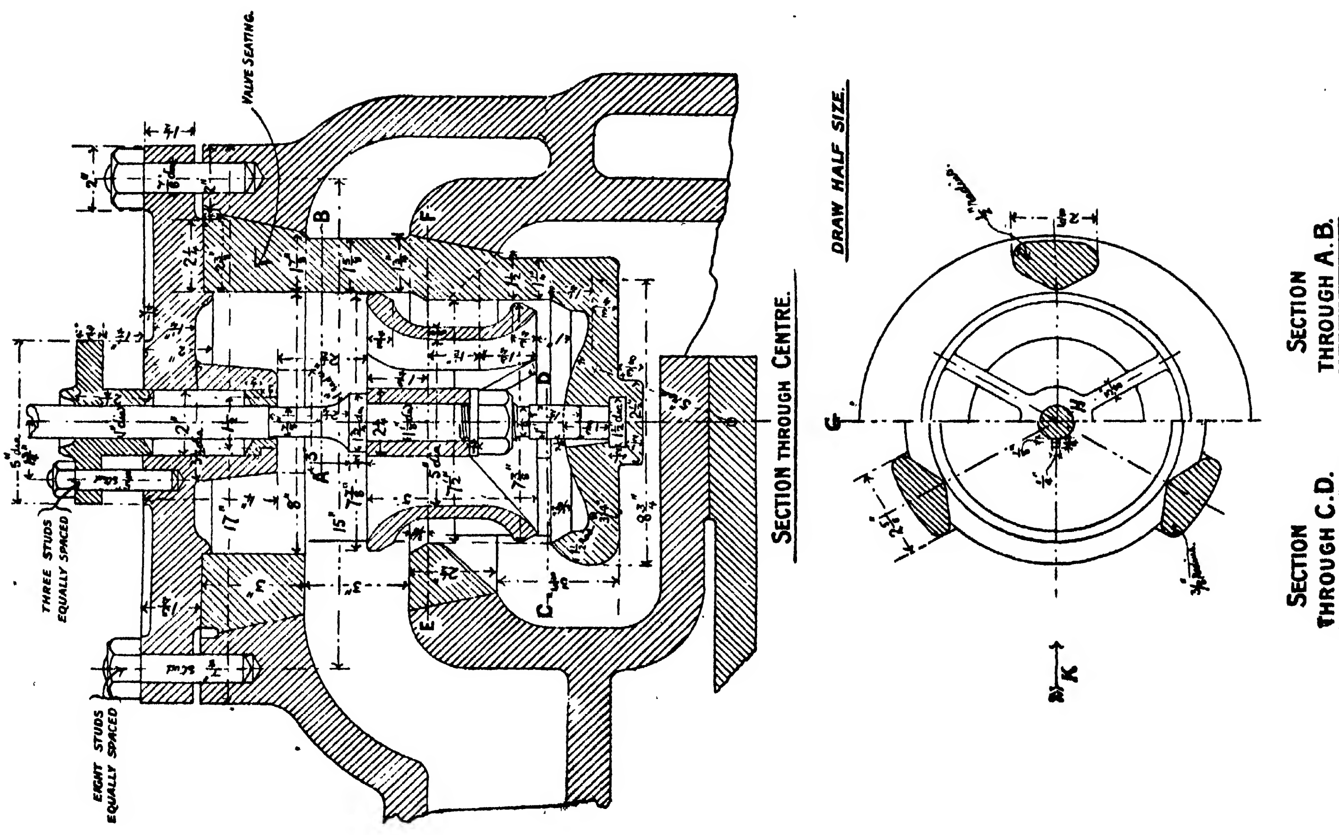


FIG. 296.—Equilibrium Admission Valve.

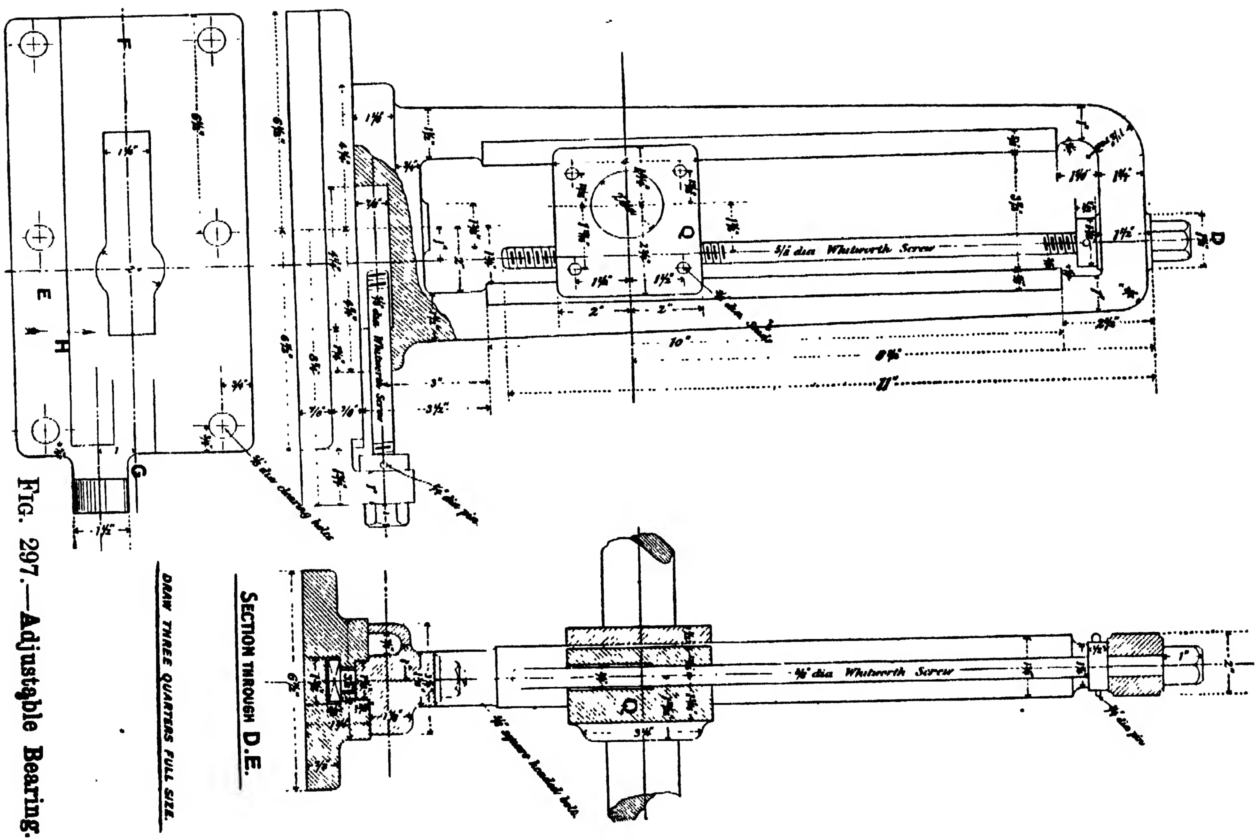


FIG. 297.—Adjustable Bearing.

Questions.

The Sketches in answer to these questions should be drawn freehand, and are to be drawn either in pencil or ink.

1. Sketch, in good proportion, giving a few leading dimensions, a muff or box coupling for the connection of two lengths of a machine shop main shaft 3 inches diameter.

2. How would you proceed to mark off and machine the block **Q**, Fig. 297, in order to ensure that the centre line of the hole for the boring bar is exactly parallel to the sliding surfaces and perpendicular to the direction of vertical sliding?

3. The leading screw of a lathe is right-handed and has 4 threads per inch. It is required to cut a right-hand screw 8 threads per inch. Sketch a suitable train of wheels, and indicate by the sketch how the wheels are supported. Assume that the wheel on the mandril has 20 teeth.

4. Make a sketch of a switch for carrying a continuous current of 100 ampères, showing it in position on a switchboard. The circuit voltage is about 200.

5. Sketch a gib and cotter connecting rod end, and show clearly how the cotter is prevented from slacking back.

Draw either Example 1 or *Alternative Example* 2, but not both.

Also answer any *two*, but not more than *two* of the questions numbered 1 to 5.

Trace in Indian ink on the tracing paper supplied the drawing shown.

Example 1.

Tumbling Bearing.

The details of a tumbling bearing for a lathe are given on p. 276. The bearing is designed to support the long shaft at the back of a lathe in such a way that a boss projecting from the lathe saddle and encircling the shaft may pass the bearing freely in either direction. The boss moves with the saddle along the lathe bed, and eventually comes in contact with the tumbling bearing, which it gradually displaces. The bearing falls sufficiently far below the shaft to allow of the passage of the boss. The tumbling bearing is restored to its vertical position after lateral displacement, and is maintained in the vertical position by the action of the bell-crank balance-weight levers gearing with the inclined ends of the vertical levers attached to the bearing supporting the long shaft.

You are required to draw to a scale of one-half full size:

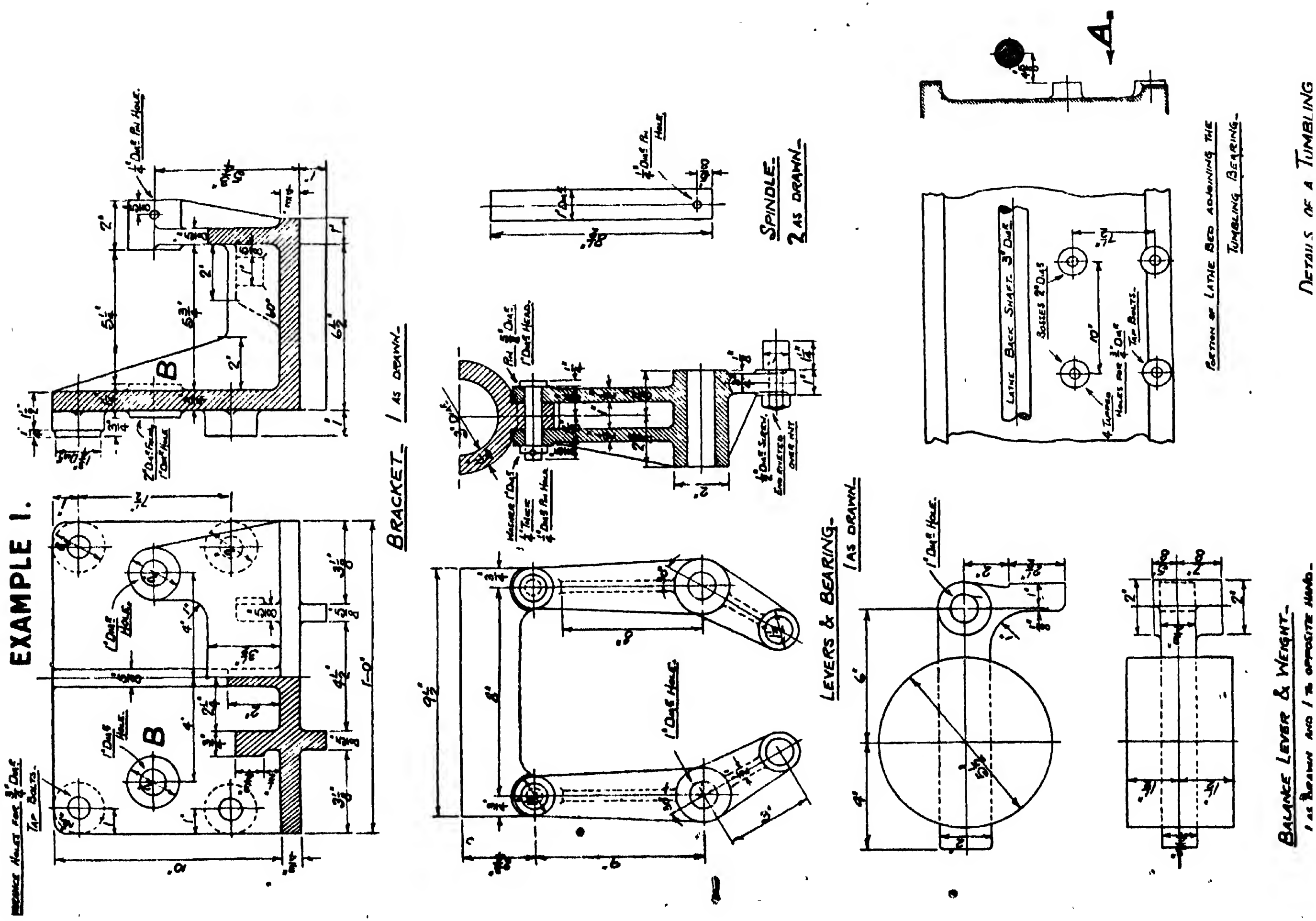
(*a*) The left half of the outside elevation seen when looking in the direction of the arrow **A**. Show all the parts assembled together, so that the bearing stands in its normal position.

Note.—The dotted lines required to show the outlines of the hidden parts of the levers must be shown in this view.

(*b*) Project from the half outside elevation (*a*) the outside end elevation.

Note.—Dotted lines need not be shown in this view.

Dimension lines are not required in either view.


EXAMPLE I.
BRACKET_ 1 AS DRAWN_
SPINDLE_ 2 AS DRAWN_
LEVERS & BEARING_ 1 AS DRAWN_
BALANCE LEVER & WEIGHT_ 1 AS DRAWN AND 1 TO OPPOSITE HAND_
PORTION OF LATHE BED ADJOINING THE TUMBLING BEARING_
DETAILS OF A TUMBLING
LATHE BACK SHAFT 3" DIA.
BOSSES 2" DIA.
A
B

Alternative Example 2.

Engine Cylinder.

The drawings of this example show one of a pair of cylinders for a vertical steam-engine. Neither the cylinder cover nor the steam-chest cover are shown.

Arranging the vertical centre line of the cylinder lengthways of the paper, in order to have room to place the required views in their proper relative positions, draw to a scale of one-half full size:

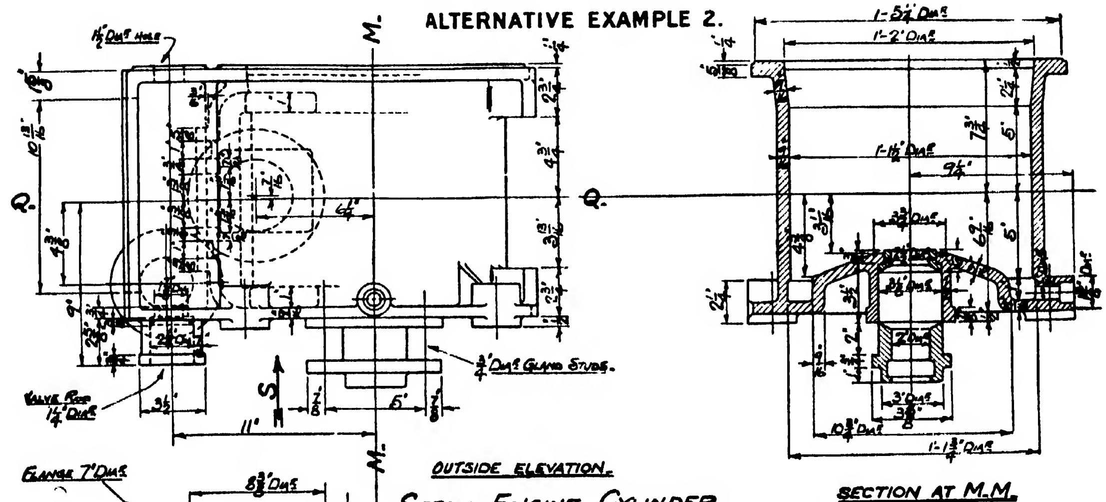
(*c*) In the place of the outside elevation shown, a sectional elevation of the part to the left of **MM**, taking the section through **PP**.

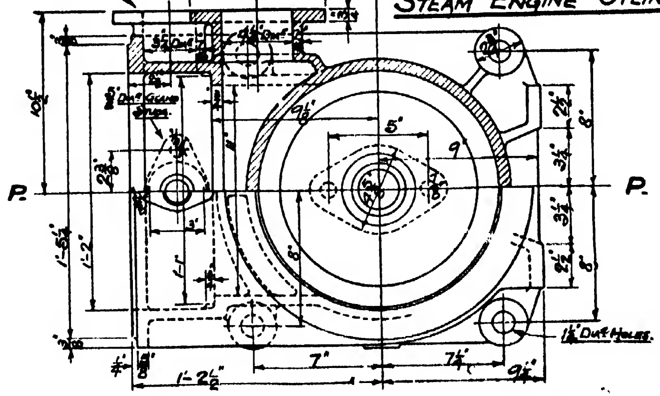
(*d*) An outside view, looking in the direction of the arrow **S**, of the portion you have drawn in section in answer to (*c*).

Note.—In neither of these views are you required to show the piston rod, gland, gland studs and neck bush, the cylinder cover, and the steam-chest cover.

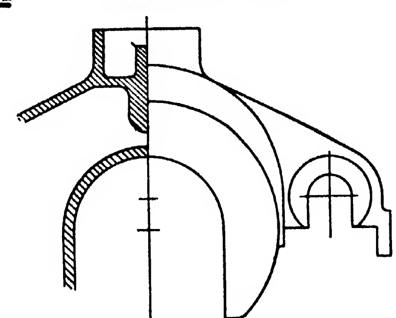
Neither dotted lines nor dimension lines need be shown.

ALTERNATIVE EXAMPLE 2.





STEAM ENGINE CYLINDER.



DRAWING TO BE TRACED.

Questions—only two to be answered.

The sketches and answers to these questions are to be drawn freehand, either in pencil or in ink, near the written answer on the squared foolscap paper attached to the drawing paper. The sketches must not be made on the drawing paper.

1. Make a careful freehand sketch of a lubricator of the kind used on the crank end of a connecting rod. Show how the oil is brought to the bearing, and very briefly explain the action of the lubricator. You may select a type of crank end suitable for either a locomotive or a marine engine, or a horizontal stationary engine.

2. Calculate the thickness of plate for a cylindrical boiler shell, 5 feet diameter inside, so that there shall be a factor of safety of 6 when the boiler pressure is 200 pounds per square inch. Assume that the strength of the longitudinal riveted joint is 70 per cent. of the strength of the plate and that the ultimate strength of the plate is 30 tons per square inch.

3. Make a bold freehand sketch of a 1-inch stud screwed to the Whitworth standard thread along 2 inches from one end and long enough to allow a distance of $2\frac{1}{2}$ inches from the face of the boss into which it is screwed to the other end. Explain, with the aid of sketches, how you would screw the stud securely in place.

4. Make a sketch showing how a condenser tube is packed in a tube plate. Assume a tube $\frac{3}{4}$ inch outside diameter and a tube plate 1 inch thick.

5. The crank shaft of a petrol engine is coupled to the armature shaft of a dynamo. Sketch any form of coupling which will allow for a deviation of exact alignment in the two shafts.

Table I.

USEFUL NUMBERS AND FORMULÆ.

$\sqrt{2}=1\cdot414$, $\sqrt{3}=1\cdot732$, $\sqrt{5}=2\cdot236$, $\sqrt{6}=2\cdot449$.

$\pi=3\cdot1416$ or $3\cdot142$ or $\frac{22}{7}$. $\frac{1}{\pi}=0\cdot3183$.	
$\pi^2=9\cdot872$. 1 inch $=2\cdot54$ cm.	$\log \pi = 0\cdot4972$
1 lb. $=453\cdot6$ grams, $2\frac{1}{5}$ lbs. $=1$ kilogram.	$\log 2\cdot718=0\cdot4343$
1 gallon of water $=10$ lbs. $=0\cdot1604$ cub. ft.	$\log \cdot7854=\bar{1}\cdot8951$
1 cubic foot of water $=62\cdot3$ lbs.	$\log 62\cdot3=1\cdot7945$
Volts $\times$ ampères $=$ watts.	$\log 1728=3\cdot2375$
1 horse-power $=33000$ ft.-lbs. per min.	$\log \cdot5236=\bar{1}\cdot7190$
$=746$ watts.	$\log \cdot1605=\bar{1}\cdot2054$
1 radian $=57\cdot3$ degrees.	

To convert common into Naperian logarithms, multiply by $2\cdot3026$ ($e=2\cdot718$).

Mensuration Formulae. In the following formulae: A denotes area; S, surface; V, volume; a, b, c, the sides of a figure; h, the altitude; l, the slant height; R and r, radii of circles.

Rectangle *or Parallelogram.* $A=ah$.

Triangle. $A=\frac{1}{2}ah$, or $\sqrt{s(s-a)(s-b)(s-c)}$, where $s=\frac{1}{2}(a+b+c)$.

Trapezium. Parallel sides a and b. $A=\frac{1}{2}(a+b)h$.

Circle. Circumference $=2\pi r$, $A=\pi r^2$ or $\pi(R^2-r^2)$.

Ellipse. Semi-axes a and b. $A=\pi ab$.

Simpson's Rule. $A=\frac{s}{3}(A_1+4B+2C)$ where s is the space or distance between two consecutive ordinates. A_1 is the sum of first and last ordinates, B is sum of even, and C is sum of the odd ordinates.

Prism. $S=2(ab+bc+ac)$, $V=abc$, diagonal $=\sqrt{a^2+b^2+c^2}$.

Cylinder. $S=2\pi rh+2\pi r^2$, $V=\pi r^2h$.

Cone. $S=\pi rl+\pi r^2$, $V=\frac{1}{3}\pi r^2h$.

Sphere. $S=4\pi r^2$, $V=\frac{4}{3}\pi r^3=0\cdot5236d^3$.

Ring. $S=4\pi^2Rr$, $V=2\pi^2r^2R$.

Weight in lbs. per cub. in.:—Cast iron, 0·26; Wrought iron, 0·28; Steel, 0·29; Brass, 0·298; Copper, 0·319; Lead, 0·414.

Table II.

LOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	9	13	17	21	26	30	34	38
											4	8	12	16	20	24	28	32	36
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	12	15	19	23	27	31	35
											4	7	11	15	19	22	26	30	33
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	11	14	18	21	25	28	32
											3	7	10	14	17	20	24	27	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	7	10	13	16	20	23	26	30
											3	7	10	13	16	19	22	25	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	19	22	25	28
											3	6	9	12	15	17	20	23	26
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	9	11	14	17	20	23	26
											3	6	8	11	14	17	19	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	14	16	19	22	24
											3	5	8	10	13	16	18	21	23
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	3	5	8	10	13	15	18	20	23
											2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
											2	5	7	9	11	14	16	18	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
											2	4	6	8	11	13	15	17	19
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8

Table II.

LOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4

Table III.

ANTILOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	[illegible]	5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	4	5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6

Table III.

ANTILOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

Table IV.

CHORDS OF ANGLES.

Deg.	0′	10′	20′	30′	40′	50′	Deg.	0′	10′	20′	30′	40′	50′
0	·000	·003	·006	·009	·012	·014	45	·765	·768	·771	·773	·776	·779
1	·017	·020	·023	·026	·029	·032	46	·781	·784	·787	·789	·792	·795
2	·035	·038	·041	·044	·046	·049	47	·797	·800	·803	·805	·808	·811
3	·052	·055	·058	·061	·064	·067	48	·813	·816	·819	·821	·824	·827
4	·070	·073	·076	·078	·081	·084	49	·829	·832	·835	·837	·840	·843
5	·087	·090	·093	·096	·099	·102	50	·845	·848	·850	·853	·856	·858
6	·105	·108	·110	·113	·116	·119	51	·861	·864	·866	·869	·871	·874
7	·122	·125	·128	·131	·134	·137	52	·877	·879	·882	·885	·887	·890
8	·139	·142	·145	·148	·151	·154	53	·892	·895	·898	·900	·903	·905
9	·157	·160	·163	·166	·168	·171	54	·908	·911	·913	·916	·918	·921
10	·174	·177	·180	·183	·186	·189	55	·923	·926	·929	·931	·934	·936
11	·192	·195	·197	·200	·203	·206	56	·939	·941	·944	·947	·949	·952
12	·209	·212	·215	·218	·221	·223	57	·954	·957	·959	·962	·964	·967
13	·226	·229	·232	·235	·238	·241	58	·970	·972	·975	·977	·980	·982
14	·244	·247	·249	·252	·255	·258	59	·985	·987	·990	·992	·995	·997
15	·261	·264	·267	·270	·273	·275	60	1·000	1·003	1·005	1·007	1·010	1·013
16	·278	·281	·284	·287	·290	·293	61	1·015	1·018	1·020	1·023	1·025	1·028
17	·296	·298	·301	·304	·307	·310	62	1·030	1·033	1·035	1·037	1·040	1·042
18	·313	·316	·319	·321	·324	·327	63	1·045	1·047	1·050	1·052	1·055	1·057
19	·330	·333	·336	·339	·342	·344	64	1·060	1·062	1·065	1·067	1·070	1·072
20	·347	·350	·353	·356	·359	·362	65	1·075	1·077	1·079	1·082	1·084	1·087
21	·364	·367	·370	·373	·376	·379	66	1·089	1·092	1·094	1·097	1·099	1·101
22	·382	·384	·387	·390	·393	·396	67	1·104	1·106	1·109	1·111	1·113	1·116
23	·399	·402	·404	·407	·410	·413	68	1·118	1·121	1·123	1·126	1·128	1·130
24	·416	·419	·421	·424	·427	·430	69	1·133	1·135	1·138	1·140	1·142	1·145
25	·433	·436	·438	·441	·444	·447	70	1·147	1·149	1·152	1·154	1·157	1·159
26	·450	·453	·456	·458	·461	·464	71	1·161	1·164	1·166	1·168	1·171	1·173
27	·467	·470	·472	·475	·478	·481	72	1·176	1·178	1·180	1·183	1·185	1·187
28	·484	·487	·489	·492	·495	·498	73	1·190	1·192	1·194	1·197	1·199	1·201
29	·501	·504	·506	·509	·512	·515	74	1·204	1·206	1·208	1·211	1·213	1·215
30	·518	·520	·523	·526	·529	·532	75	1·217	1·220	1·222	1·224	1·227	1·229
31	·534	·537	·540	·543	·546	·548	76	1·231	1·234	1·236	1·238	1·240	1·243
32	·551	·554	·557	·560	·562	·565	77	1·245	1·247	1·250	1·252	1·254	1·256
33	·568	·571	·574	·576	·579	·582	78	1·259	1·261	1·263	1·265	1·268	1·270
34	·585	·587	·590	·593	·596	·599	79	1·272	1·274	1·277	1·279	1·281	1·283
35	·601	·604	·607	·610	·612	·615	80	1·286	1·288	1·290	1·292	1·294	1·297
36	·618	·621	·624	·626	·629	·632	81	1·299	1·301	1·303	1·305	1·308	1·310
37	·635	·637	·640	·643	·646	·648	82	1·312	1·314	1·316	1·319	1·321	1·323
38	·651	·654	·657	·659	·662	·665	83	1·325	1·327	1·330	1·332	1·334	1·336
39	·668	·670	·673	·676	·679	·681	84	1·338	1·340	1·343	1·345	1·347	1·349
40	·684	·687	·689	·692	·695	·698	85	1·351	1·353	1·355	1·358	1·360	1·362
41	·700	·703	·706	·709	·711	·714	86	1·364	1·366	1·368	1·370	1·372	1·375
42	·717	·719	·722	·725	·728	·730	87	1·377	1·379	1·381	1·383	1·385	1·387
43	·733	·736	·738	·741	·744	·746	88	1·389	1·391	1·393	1·396	1·398	1·400
44	·749	·752	·755	·757	·760	·763	89	1·402	1·404	1·406	1·408	1·410	1·412

Table V.

WHITWORTH STANDARD SCREW THREADS.

d Diameter of bolt in inches.		Number of threads per inch.	d_1 Diameter at bottom of thread.	Area of Cross-section at bottom of thread in square inches.	Width W Across flat sides.	Distance across corners.
⅜	·375	16	0·295	0·068	0·709	0·819
½	·5	12	·393	·1214	·919	1·06
⅝	·625	11	·508	·2027	1·10	1·27
¾	·75	10	·622	·3039	1·30	1·50
⅞	·875	9	·733	·4220	1·48	1·71
1	1	8	·840	·5543	1·67	1·93
1⅛	1·125	7	·942	·6971	1·86	2·15
1¼	1·25	7	1·067	·8935	2·05	2·37
1⅜	1·375	6	1·162	1·061	2·21	2·56
1½	1·5	6	1·287	1·301	2·41	2·79
1⅝	1·625	5	1·369	1·472	2·58	2·97
1¾	1·75	5	1·494	1·754	2·76	3·18
1⅞	1·875	4·5	1·590	1·986	3·02	3·49
2	2	4·5	1·720	2·324	3·15	3·64
2⅛	2·125	4·5	1·840	2·659	3·34	3·85
2¼	2·25	4·0	1·930	2·926	3·55	4·09
2⅜	2·375	4·0	2·055	3·318	3·75	4·33
2½	2·5	4·0	2·180	3·734	3·89	4·50
2⅝	2·625	4·0	2·305	4·172	4·05	4·68
2¾	2·75	3·5	2·384	4·464	4·18	4·83
2⅞	2·875	3·5	2·509	4·942	4·35	5·02
3	3	3·5	2·634	5·451	4·53	5·23
3¼	3·25	3·25	2·855	6·401	4·85	5·60
3½	3·5	3·25	3·105	7·573	5·17	5·98
3¾	3·75	3·0	3·323	8·673	5·55	6·41
4	4	3·0	3·573	10·027	5·95	6·87
4¼	4·25	2·875	3·804	11·37	6·37	7·36
4½	4·5	2·875	4·054	12·91	6·82	7·88
4¾	4·75	2·75	4·284	14·41	7·30	8·43
5	5	2·75	4·534	16·14	7·80	9·01
5¼	5·25	2·625	4·762	17·81	8·35	9·64
5½	5·5	2·625	5·012	19·72	8·85	10·22
5¾	5·75	2·5	5·238	21·55	9·45	10·91
6	6	2·5	5·488	23·65	10·0	11·55

ANSWERS TO EXERCISES.

EXERCISES II. p. 44.

14. By shearing. **15.** 1·78″. **16.** By shearing **17.** 2·078″, 1·813″. **19.** 55·6 %. **21.** 1·69″

EXERCISES III. p. 65.

18. $\frac{3}{4}$″ (d_1 = 0·598″). **19.** $2\frac{5}{8}$″ (d_1 = 2·309). **20.** $2\frac{3}{4}$″ (d_1 = 2·345).

24.

d	1″	$1\frac{1}{2}$″	$2\frac{1}{2}$″	3″
p	0·125″	0·165″	0·245″	0·285″
n	8	6	4	3·5
d_1	0·84″	1·27″	2·11″	2·54″

25. $\frac{7}{8}$″.

26. 1·17″.

27. 1·9 tons.

28. $d_1 = 0·63$″, $d = \frac{3}{4}$″.

EXERCISES V. p. 92.

7. 12′ 6″. **8.** 60 rev. per min.; $34\frac{2}{7}$″, $13\frac{5}{7}$″. **12.** $1028\frac{4}{7}$; $257\frac{1}{7}$ rev. per min.

13. 47·13 ft.; 352·8 rev. per min. **14.** 24 in.: 42 in.

EXERCISES VIII. p. 138.

9. $\frac{19}{32}$″, (0·5978″).

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